Chapter 5

Results and Discussions

The present study mainly deals with the analysis of the sound absorption coefficient of kapok and Estabragh natural fibre nonwoven fabric, their physical properties, and its effect on the sound absorption coefficient. The results are categorized according to the proportion of Kapok and Estabragh (Milkweed) fibre in the blend, carded web mass per unit area, needle depth and stroke frequency of the needle punch machine at different sound wave frequencies. Effect of fabric thickness, fabric GSM, air permeability, porosity, etc., are discussed here concerning the sound absorption coefficient of fabrics at different sound wave frequencies. The factors and the physical properties that affect the sound absorption coefficient (α) significantly are highlighted here for more clarification. For the proper analysis of the data generated during the present study, the results and discussion have been separately discussed for Kapok and Estabragh fibre using various statistical tools as follows.

- Interactive effect of different process parameters on the sound absorption coefficient.
- Effect of proportion of fibre in the blend on the sound absorption coefficient.
- Effect of carded web mass on the sound absorption coefficient.
- Effect of stroke frequency on the sound absorption coefficient.
- Effect of needle depth on the sound absorption coefficient.
- Effect of fabric thickness on the sound absorption coefficient.
- Effect of fabric GSM on the sound absorption coefficient.

- Effect of fabric air permeability on the sound absorption coefficient.
- Effect of fabric porosity on the sound absorption coefficient.
- Interactive effect of different physical properties on the sound absorption coefficient.
- Validation test results of experimental setup.

5.1 Kapok Fibre

5.1.1 Interactive effect of different process parameters on the sound absorption coefficient

The effect of the process variable viz proportion of kapok fibre in the blend, carded web mass, stroke frequency and needle depth on the sound absorption coefficient of kapok fibre nonwoven fabric has been taken into consideration by using the response surface methodology based on the central composite design. The data obtain from Minitab 18 is given in Appendix I, indicate the DOE planned using Minitab 18 software according to RSM-CCD methods. Four continuous factors like Kapok fibre proportion in the blend% X_1, carded web mass (g/m^2) X_2, stroke frequency (/min) X_3 of needle punch machine, needle depth (mm) X_4, and one categorical factor sound frequency (Hz) X_5 selected for DOE. The sound absorption coefficient results fed in the table as a response to carry out the further analysis of data.

In this study, sound absorption coefficient results are analyzed using the response surface method with the help of Minitab 18 software. The average value of obtained results of sound absorption coefficient of the kapok fibre nonwoven fabric for different variables are enumerated in Appendix – I (Table 2).

5.1.1.1 Interactive effect of kapok fibre blend% and carded web mass on sound absorption coefficient

The contour plot in Figure 5.1 shows the effects of kapok fibre blend% and carded web mass (g/m^2) on sound absorption coefficient for certain hold values of stroke frequency, needle depth and sound wave frequency. As indicated in Figure 5.1, the proportion of kapok fibre in the blend% and carded web mass have considerable influence on the sound

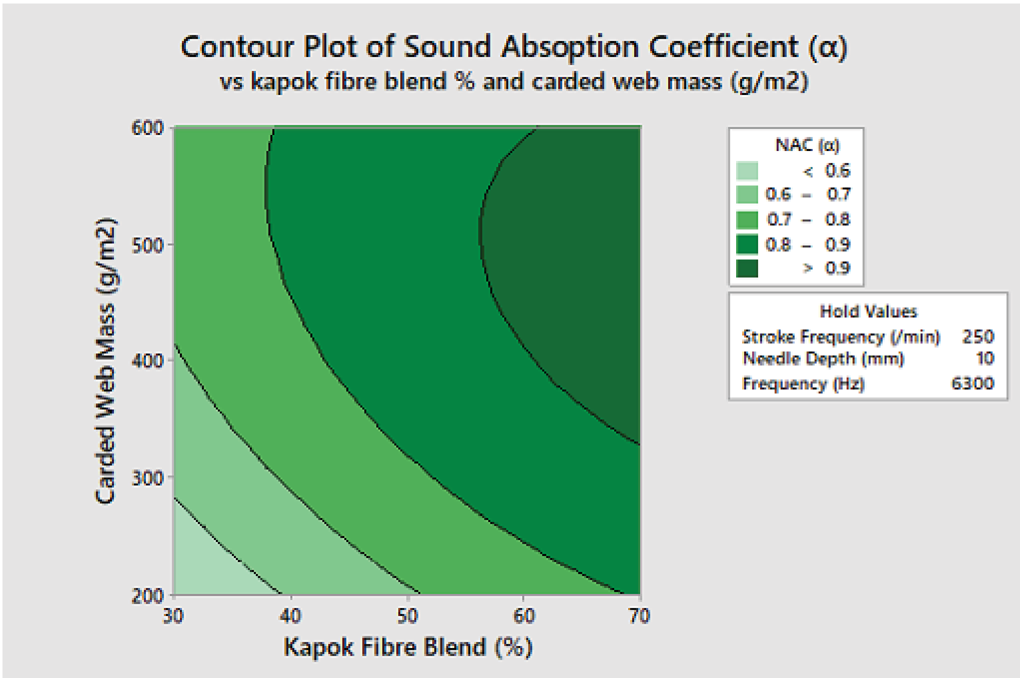

Figure 5.1: Effect of kapok fibre blend% and carded web mass on sound absorption coefficient

absorption coefficient. The highest values of the sound absorption coefficient are in the upper right corner of the plot, which corresponds with high values of both kapok fibre blend% and carded web mass (g/m^2). The lowest values of the sound absorption coefficient are in the lower left corner of the plot, which corresponds with low values of kapok fibre blend% and carded web mass (g/m^2). The lowest value of the sound absorption coefficient was achieved at 30% kapok fibre proportion in the blend and carded web mass 200 g/m^2. The highest sound absorption value was achieved for kapok fibre blend% 70 and 600 g/m^2 carded web mass. The sound absorption value >0.9 was achieved with kapok fibre proportion in blend 59 to 70% and carded web mass 350 g/m^2 to 600 g/m^2. It is clear from the graph that as the proportion of kapok fibre in the blend increased the sound absorption coefficient also increase. A nonwoven fabric made of kapok fibre has a higher surface area of fibre in the fabric due to the low density and fineness of kapok fibre, which leads to an increase in the sound absorption of the fabric [44, 79]. Another reason for the increase in the sound absorption coefficient is the hollow structure of kapok fibre, hollow fibre due to entrapment of air in their hollow lumen is expected to increase the sound absorption properties of the material by twofold [176]. Therefore, an increment in the kapok fibre proportion of the blends leads to more frictional losses and a higher sound absorption coefficient. Figure 5.1 shows that as the carded web mass of the nonwoven fabric increase, there is a linear increase in the sound absorption coefficient. The minimum value of the sound absorption coefficient was achieved for carded web mass 200 g/m^2 and the highest value at carded web mass 600 g/m^2 was achieved. Increase in the carded web mass increase the number of fibre in the nonwoven fabric structure, so when the sound wave interacts with the nonwoven fabric it offers higher resistance to the incident sound wave due to increase in the air/fibre boundaries [37, 79, 177] and gives higher sound absorption coefficient values of nonwoven fabric.

5.1.1.2 Interactive effect of kapok fibre blend% and stroke frequency on sound absorption coefficient

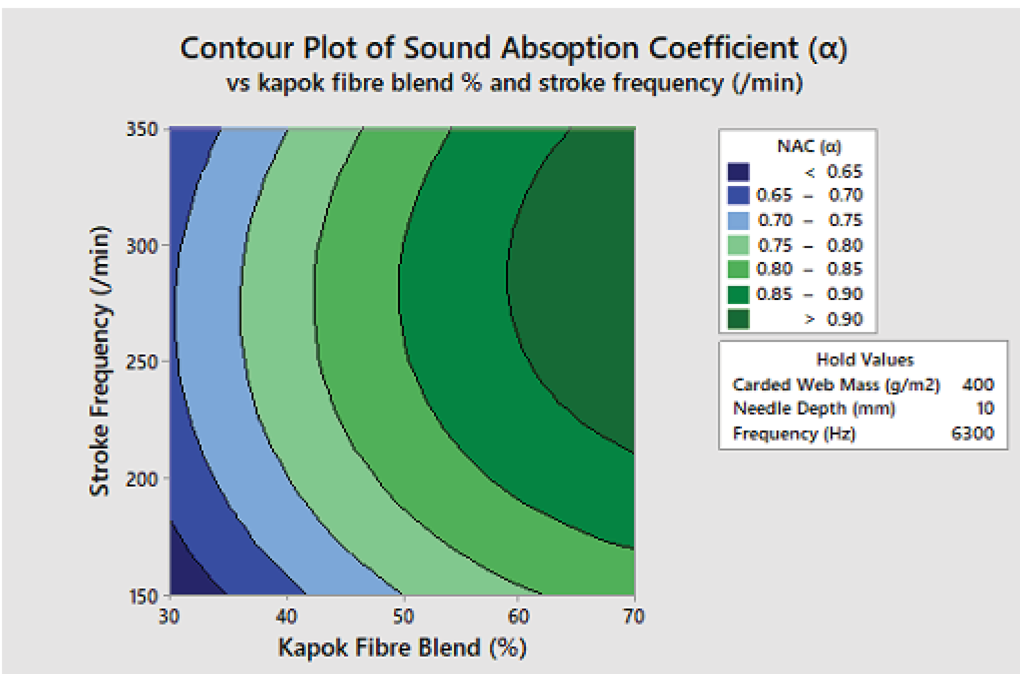

Figure 5.2: Effect of kapok fibre blend% and stroke frequency on sound absorption coefficient

The results of the sound absorption coefficient for a different proportion of kapok fibre in the blend% and stroke frequency are shown in Appendix I (Table 2). The contour plot in Figure 5.2 shows the effects of kapok fibre blend% and stroke frequency on sound absorption coefficient for certain hold values of carded web mass, needle depth and frequency. As indicated in Figure 5.2, the proportion of kapok fibre in the blend% and stroke frequency have considerable influence on the sound absorption coefficient. The highest values of the sound absorption coefficient are in the upper right corner of the plot, which corresponds with high values of both kapok fibre blend% and stroke frequency. The lowest values of the sound absorption coefficient are in the lower left corner of the plot, which corresponds with low values of kapok fibre blend% and stroke frequency (/min). The lowest value of the sound absorption coefficient was achieved with a 30% kapok fibre proportion in the blend and 150 strokes per minute. The highest sound absorption value was achieved for 70% proportion of kapok fibre in the blend and 350 strokes per minute. The sound absorption value >0.9 was achieved with 60 to 70% of kapok fibre proportion in blend and stroke frequency 210/min to 350/min. It is clear from the graph that as the proportion of kapok fibre in the blend increased the sound absorption coefficient also increase. A nonwoven fabric made of kapok fibre gives higher sound absorption due to its hollow structure, low density and fineness [44, 176]. Figure 5.2 shows that as the stroke of the nonwoven fabric increase, there is an increase in the sound absorption coefficient. The minimum value of the sound absorption coefficient was achieved with stroke frequency 150/min and the highest value with 350/min stroke frequency was achieved. Increase the stroke frequency along with an increase in the blend% significantly affect the sound absorption coefficient. The stroke frequency from 210/min to 350/min gives the best results. An increase in the stroke frequency gives good sound absorption properties because of an increase in the pore in the nonwoven structure, which entraps the sound wave in the structure. Furthermore, an increase in the stroke frequency makes the fabric more compact, because of which the average pore size decrease with more pore per unit area. These small pores create hindrances to the sound wave passage and also increase the friction resistance, thereby increasing the sound absorption properties of the fabric [38, 177].

5.1.1.3 Interactive effect of kapok fibre blend% and needle depth on sound absorption coefficient

The results of the sound absorption coefficient for a different proportion of kapok fibre in the blend% and needle depth are shown in Appendix I (Table 2). The contour plot in Figure 5.3 shows the effects of kapok fibre blend% and needle depth on sound absorption coefficient for certain hold values of carded web mass, stroke frequency and sound wave

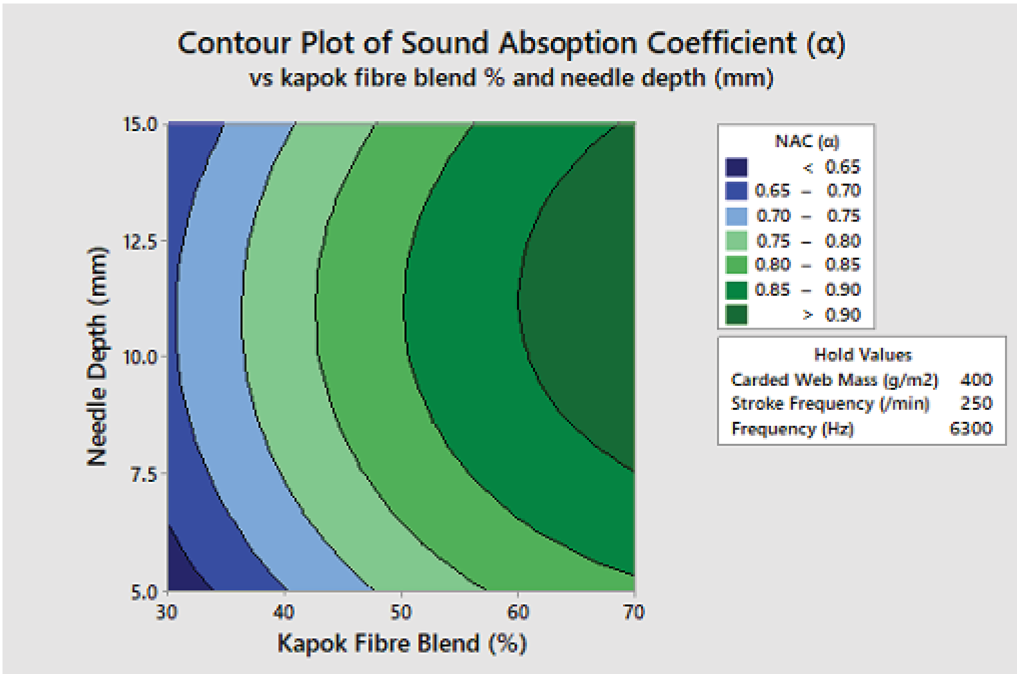

Figure 5.3: Effect of kapok fibre blend% and needle depth on sound absorption coefficient

frequency. As indicated in Figure 5.3, the proportion of kapok fibre in the blend% and needle depth have considerable influence on the sound absorption coefficient. The highest values of the sound absorption coefficient are in the upper right corner of the plot, which corresponds with high values of both kapok fibre blend% and needle depth. The lowest values of the sound absorption coefficient are in the lower left corner of the plot, which corresponds with low values of kapok fibre blend% and needle depth (mm). The lowest value of the sound absorption coefficient was achieved with a 30% kapok fibre proportion in the blend and 5 mm needle depth. The highest sound absorption value was achieved for kapok fibre blend% 70 and 15 mm needle depth. The sound absorption value >0.9 was achieved with 60 to 70% of kapok fibre proportion in blend and needle depth 7.5 mm to 15 mm. It is clear from the graph that as the proportion of kapok fibre in the blend increased the sound absorption coefficient also increase. A nonwoven fabric made of kapok fibre gives higher sound absorption due to its hollow structure, low density and fineness [44,176]. Figure 5.3 shows that as the needle depth increase, there is an increase in the sound absorption coefficient. The lowest value of the sound absorption coefficient was achieved with needle penetration depth 5 mm and the highest value at 15 was achieved. Increasing the needle depth along with an increase in the blend% significantly affects the sound absorption coefficient. But for the same fibre blend% increase in needle depth from 7.5 to 15 mm does not show any significant improvement in the sound absorption properties of the fabric. It was observed that needle depth 10 mm to 12 mm show good sound absorption properties for each kapok fibre blend% value. An increase in the needle depth gives good sound absorption properties because of the intense fibre entanglement, which increases in numbers of small pore size that entrap the sound wave in the structure. More number of small pores increase the frictional resistance to a sound wave, because of which the more energy dissipated and increase the sound absorption properties of the nonwoven fabric [79, 176].

5.1.1.4 Interactive effect of carded web mass and stroke frequency on sound absorption coefficient

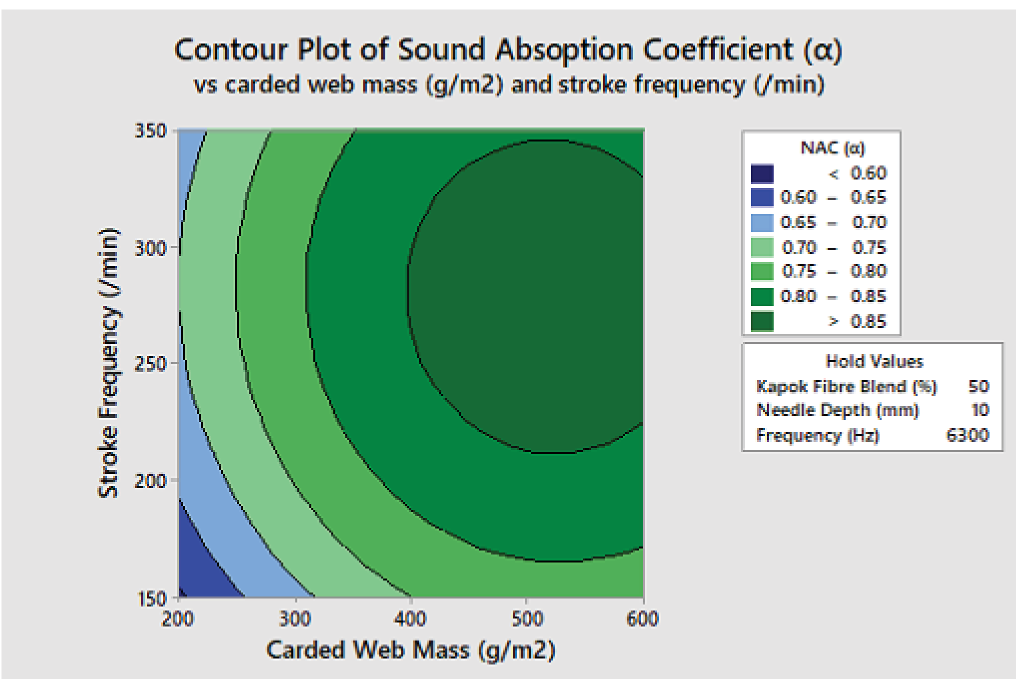

Figure 5.4: Effect of carded web mass and stroke frequency on the sound absorption coefficient

The contour plot in Figure 5.4 shows the effects of carded web mass (g/m^2) and stroke frequency (/min) on sound absorption coefficient of kapok fibre nonwoven fabric for certain hold values of kapok fibre blend%, needle depth and frequency. Figure 5.4, show that the proportion of carded web mass and stroke frequency have a significant effect on the sound absorption property of kapok fibre nonwoven fabric at 6300 Hz frequency as all values are above 0.5. The highest values of the sound absorption coefficient are in the upper right corner of the plot, which corresponds with high values of both carded web mass (g/m^2) and stroke frequency (/min). The lowest values of the sound absorption coefficient are in the lower left corner of the plot, which corresponds with low values of carded web mass (g/m^2) and stroke frequency (/min). The lowest value of the sound absorption coefficient was achieved with 200 g/m^2 carded web mass and 150/min stroke frequency. The highest sound absorption value was achieved for carded web mass 600 g/m^2 and stroke frequency 345/min. The sound absorption value >0.85 was achieved with carded web mass 400 g/m^2 to 600 g/m^2 and stroke frequency 210/min to 345/min. It is clear from the graph that as the carded web mass increased the sound absorption coefficient linearly increase. The highest value of the sound absorption coefficient was achieved for carded web mass 600 g/m^2. Increase in the carded web mass increase the number of fibre in the nonwoven fabric structure, so when the sound wave interacts with the nonwoven fabric it offers higher resistance to the incident sound wave due to increase in the air/fibre boundaries [37, 79, 177] and gives higher sound absorption coefficient values of nonwoven fabric. Figure 5.4 shows that for stroke frequency 150/ min to 350/min the sound absorption coefficient value at 6300 Hz frequency is more than 0.5, which indicates good sound absorption properties. As the stroke frequency increase, the sound absorption coefficient value increased and the best results were obtained at 210/min to 345/min stroke frequency. An increase in the stroke frequency gives good sound absorption properties because of an increase in the pore in the nonwoven structure, which entraps the sound wave in the structure. Furthermore, an increase in the stroke frequency makes the fabric more compact, because of it the average pore size decrease with more pore per unit area. These small pores create obstacles to the passage of the sound wave, because of which there is an increase in the friction resistance, therefore increasing the sound absorption properties of the fabric [38, 177].

5.1.1.5 Interactive effect of carded web mass and needle depth on sound absorption coefficient

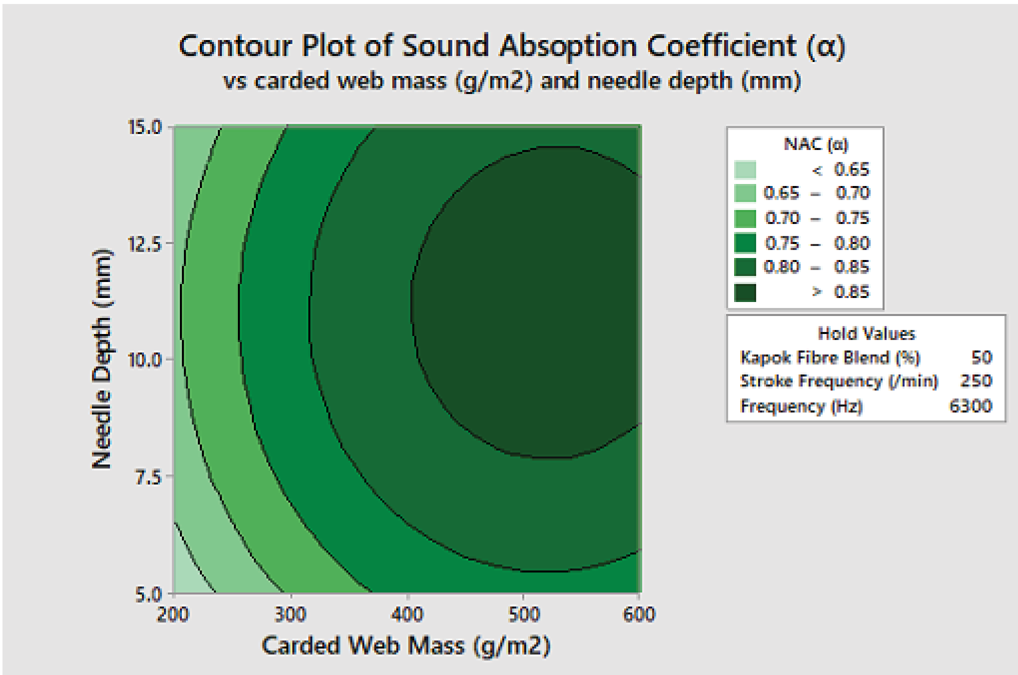

Figure 5.5: Effect of carded web mass and needle depth on the sound absorption coefficient

Figure 5.5, shows the contour plot of the interaction effect of carded web mass and needle depth on the sound absorption coefficient of kapok fibre nonwoven fabric for certain hold values of kapok fibre blend%, stroke frequency and sound wave frequency. Figure 5.5, show that the proportion of carded web mass and needle depth have a significant effect on the sound absorption property of kapok fibre nonwoven fabric at 6300 Hz frequency as all values are above 0.5. The highest values of the sound absorption coefficient are in the upper right corner of the plot, which corresponds with high values of both carded web mass (g/m^2) and needle depth (mm). The lowest values of the sound absorption coefficient are in the lower left corner of the plot, which corresponds with low values of carded web mass (g/m^2) and needle depth (mm). The lowest value of the sound absorption coefficient was achieved with 200 g/m2 carded web mass and 5 mm needle penetration depth. The highest sound absorption value was achieved for carded web mass 600 g/m^2 and needle depth 14.5 mm. The sound absorption value >0.85 was achieved with carded web mass 400 g/m^2 to 600 g/m^2 and needle depth 7.5 mm to 14.5 mm. It is clear from the graph that as the carded web mass increased the sound absorption coefficient increase linearly. The highest value of the sound absorption coefficient was achieved for carded web mass 600 g/m^2. Increase in the carded web mass increase the number of fibre in the nonwoven fabric structure, so when the sound wave interacts with the nonwoven fabric it offers higher resistance to the incident sound wave due to increase in the air/fibre boundaries [37,79,177] and gives higher sound absorption coefficient values of nonwoven fabric. Figure 5.5 shows that as the needle depth increase, there is an increase in the sound absorption coefficient. the lowest value of the sound absorption coefficient was achieved with needle penetration depth 5 mm and the highest value at 14.5 mm. Increasing the needle depth along with an increase in the carded web mass significantly affects the sound absorption coefficient. There was no significant improvement in the sound absorption properties of the fabric, with increasing needle depth from 5 mm to 7.5 mm for same fibre blend%. But as the needle depth increase from 5 mm to 10 mm shows significant improvement in the sound absorption properties of the nonwoven fabric. An increase in the needle depth gives good sound absorption properties because of the intense fibre entanglement, which increases in numbers of small pore size that entrap the sound wave in the structure. More number of small pores increase the frictional resistance to a sound wave, because of which the more energy dissipated and increase the sound absorption properties of the nonwoven fabric achieved [38, 176, 177].

5.1.1.6 Interactive effect of stroke frequency and needle depth on sound absorption coefficient

Figure 5.6 shows the contour plot of the interaction effect of stroke frequency and needle depth on the sound absorption coefficient of kapok fibre nonwoven fabric for certain hold values of kapok fibre blend%, carded web mass and frequency. As indicated in Figure 5.6, the stroke frequency and needle depth have a significant effect on the sound absorption property of kapok fibre nonwoven fabric at 6300 Hz frequency as all values are above 0.5. The highest values of the sound absorption coefficient are in the upper right side of the plot, which corresponds with stroke frequency (310/min) and needle penetration depth (12.5 mm). The lowest values of the sound absorption coefficient are in the lower left corner of the plot, which corresponds with low values of stroke frequency (/min) and needle depth (mm). The lowest value of the sound absorption coefficient was achieved with stroke

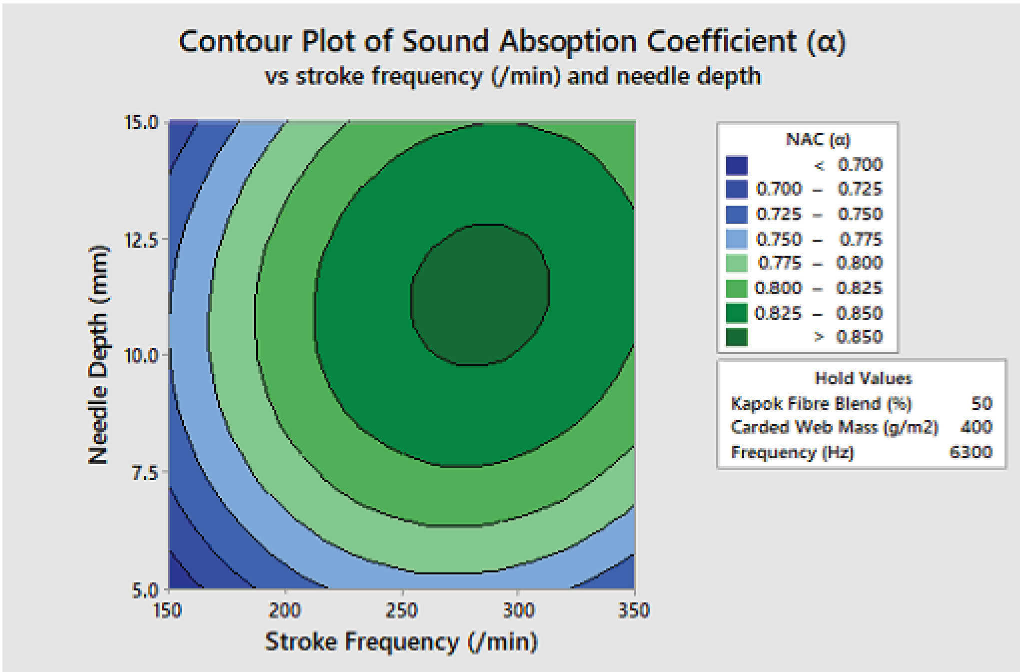

Figure 5.6: Effect of stroke frequency and needle depth on the sound absorption coefficient

frequency 150/min and 5 mm needle penetration depth. The highest sound absorption value (>0.85) was achieved with stoke frequency 250/min to 310/min and needle depth 9 mm to 13 mm. It is clear from the graph that as the stroke frequency increased from 150/min to 300/min, there was an increase in the sound absorption coefficient value. An increase in the stroke frequency makes the fabric more compact because of it the average pore size decrease with more pore per unit area. These small pores create obstacles to the path of the sound wave, because of which there is an increase in the friction resistance, therefore increasing the sound absorption properties of the fabric [38, 177]. Furthermore, Increasing the stroke frequency from 300/min to 350/min leads to a decrease in sound the sound absorption coefficient was observed. This is because an increase in the stroke frequency beyond certain values causes damage to the fibre in the structure. The highest value of the sound absorption coefficient was achieved for stroke frequency 250/min to 310/min. Figure 5.6 shows that as the needle depth increase, there is an increase in the sound absorption coefficient up to stroke frequency 300/min. Increase in the needle depth from 12.5 mm to 15 mm for stroke frequency 250 to 300/min, decrease the sound absorption coefficient value. The lowest value of the sound absorption coefficient was achieved with needle penetration depth 5 mm and 15 mm at 150/min stroke frequency and the highest value at 9 mm to 13 mm was achieved. Increasing the needle depth along with an increase in the stroke frequency up to 300/min significantly affects the sound absorption coefficient. An increase in the needle depth gives good sound absorption properties because of the intense fibre entanglement, which increases in numbers of small pore size that entrap the sound wave in the structure. More number of small pores increase the frictional resistance to a sound wave, because of which the more energy dissipated and increase the sound absorption properties of the nonwoven fabric [176, 177].

5.1.1.7 Analysis of Variance for the sound absorption coefficient of kapok fibre nonwoven fabric

The results of the sound absorption coefficient for a different proportion of kapok fibre in the blend%, carded web mass, stroke frequency and needle depth are shown in Appendix I (Table 2). Sound absorption coefficient results are analyzed using the response surface method with the help of Minitab 18 software. Four continuous factors like Kapok fibre proportion in the blend%, carded web mass (g/m^2), stroke frequency (/min) of needle punch machine, needle depth (mm), and one categorical factor sound frequency (Hz) are selected as variables and corresponding coded variable are given in Table 5.1.

Table 5.1: Coded variable of kapok fibre variables

Variables	Coded variables
Kapok fibre blend %	X_1
Carded web mass (g/m^2)	X_2
Stroke frequency (/min)	X_3
Needle depth (mm)	X_4
Frequency (Hz)	X_5

Analysis of variance (ANOVA) values for the regression model obtained from CCD employed in the optimization of process parameters. On the basis of obtained experimental values, statistical testing carried out using ANOVA test at 95% confidence level. ANOVA regression model for the sound absorption coefficient of kapok fibre nonwoven fabric given in the following Table 5.2.

Table 5.2: ANOVA regression model for the sound absorption coefficient of kapok fibre nonwoven fabric

Source	**Degree of freedom (DF)**	**Sum of squares (SS)**	**Mean of squares (MS)**	***F* Value**	***P* Value**
Model	54	17.8624	0.33079	286.46	< 0.001
Linear	12	17.6359	1.46966	1272.73	< 0.001
X_1	1	0.7385	0.7385	639.55	< 0.001
X_2	1	0.2515	0.25147	217.77	< 0.001
X_3	1	0.1098	0.1098	95.09	< 0.001
X_4	1	0.033	0.033	28.58	< 0.001
X_5	8	16.5031	2.06289	1786.48	< 0.001
Square	4	0.1595	0.03988	34.53	< 0.001
${X_1}^2$	1	0.0199	0.01989	17.23	< 0.001
${X_2}^2$	1	0.0767	0.0767	66.42	< 0.001
${X_3}^2$	1	0.0572	0.05716	49.5	< 0.001
${X_4}^2$	1	0.052	0.05195	44.99	< 0.001
2-Way Interaction	38	0.067	0.00176	1.53	0.032
X_1X_2	1	0.0086	0.00856	7.41	0.007
X_1X_3	1	0.0017	0.00167	1.44	0.231
X_1X_4	1	0.0004	0.00037	0.32	0.573
X_1X_5	8	0.0174	0.00217	1.88	0.064
X_2X_3	1	0.0002	0.00016	0.14	0.713
X_2X_4	1	0.0002	0.00016	0.14	0.713
X_2X_5	8	0.0217	0.00271	2.34	0.019
X_3X_4	1	0.0015	0.00153	1.33	0.25
X_3X_5	8	0.0118	0.00148	1.28	0.254
X_4X_5	8	0.0038	0.00047	0.41	0.915
Error	224	0.2587	0.00115		
Lack of fit	170	0.235	0.00138	3.16	< 0.001
Pure Error	54	0.0236	0.00044		

Source	**Degree of freedom (DF)**	**Sum of squares (SS)**	**Mean of squares (MS)**	***F* Value**	***P* Value**
Total	278	18.1211			
Model Summary					
Square	:	0.0339812			
R^2	:	98.57%			
R^2 (adj)	:	98.23%			
R^2 (pred)	:	97.70%			

Minitab 18 software has used for statistical data analysis. The effect of independent parameters kapok fibre proportion in blend%, carded web mass (g/m^2), stroke frequency (/min), needle depth (mm) and sound frequency (Hz) on the dependent parameter sound absorption coefficient examined for 31 kapok fibre nonwoven fabric with analysis of variance at a significance level of value p less than 0.05. The model summary and ANOVA results given in Table 5.2.

Analysis of variance (ANOVA) analysis of kapok fibre nonwoven fabric indicates that the frequency (Hz), kapok fibre blend%, carded web mass (g/m^2), stroke frequency (/min), needle depth (mm) are significantly influence the sound absorption coefficient of the nonwoven fabric because their p-value is < 0.001. According to the F values, sound frequency, kapok fibre proportion in the blend, carded web mass are more significantly influence the sound absorption coefficient than stroke frequency and needle depth.

ANOVA analysis square and 2-way interaction show that interaction between carded web mass and carded web mass, stroke frequency and stroke frequency, needle depth and needle depth, kapok fibre blend% and kapok fibre blend%, kapok fibre blend% and carded web mass, and carded web mass and frequency have p-value < 0.05, which indicate all have a significant effect on the sound absorption coefficient of the kapok fibre nonwoven fabric. It is observed that interactive effect between needle depth and frequency, carded web mass and needle depth, carded web mass and stroke frequency, kapok fibre blend% and needle depth, stroke frequency and frequency, stroke frequency and needle depth, kapok fibre blend% and stroke frequency, and kapok fibre blend% and frequency gives p-value > 0.05, which means it has less effect on the sound absorption coefficient of kapok fibre nonwoven fabric.

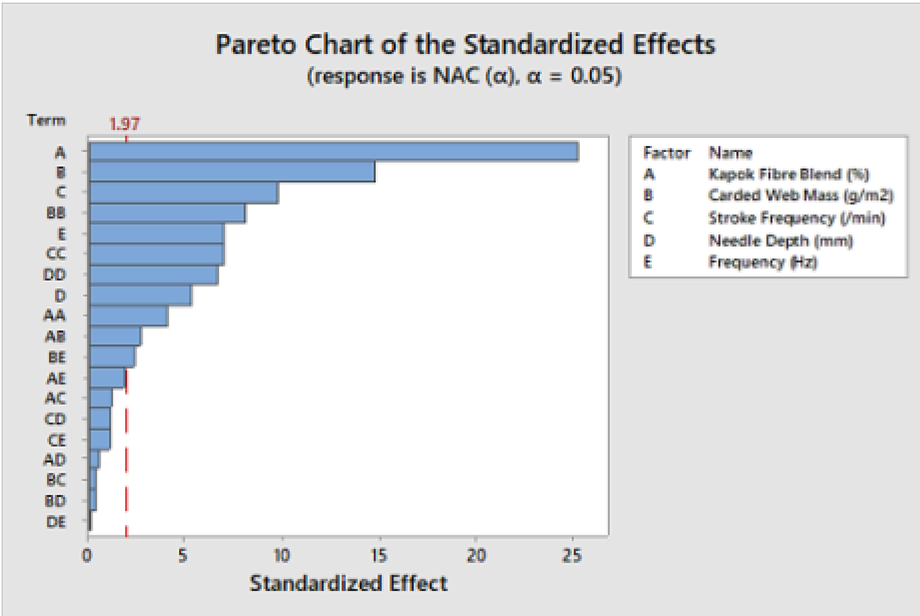

Figure 5.7: Pareto chart for process parameters of kapok fibre nonwoven fabric

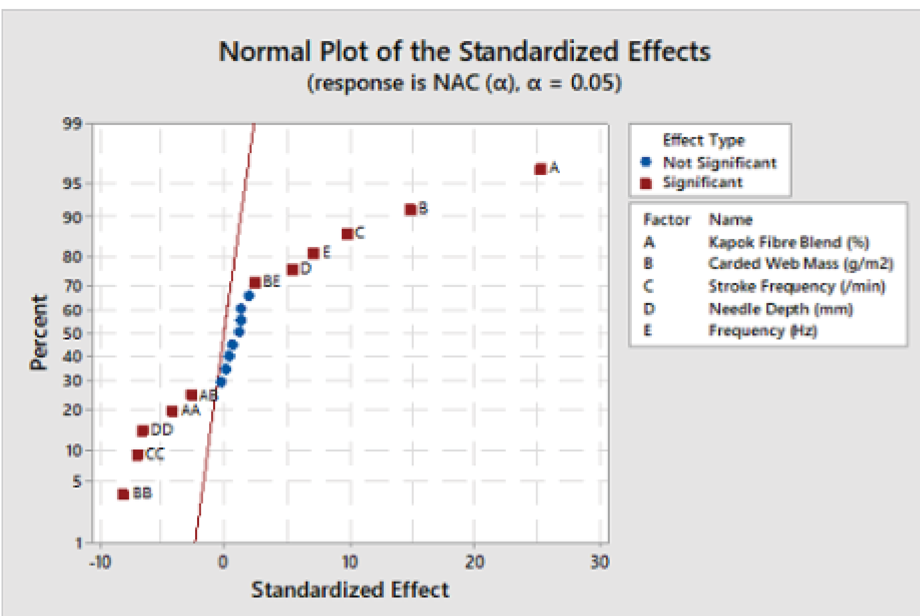

Figure 5.8: Normal plot for process parameters of kapok fibre nonwoven fabric

Table 5.2 shows the model summary that indicates that the R-sq (R-Squared "R^2") value is 98.57%. This means that the sound absorption coefficient of kapok fibre nonwoven fabric is influence by the fibre proportion in blend%, carded web mass (g/m^2), stroke frequency (/min), needle depth (mm) and sound frequency (Hz) with confidence level

98.57% and the model predicts the sound absorption coefficient successfully at a level of 97.70%. The p-value $0.001 < 0.05$ indicate the model is statistically highly significant.

Figure 5.7 and 5.8 shows the Pareto chart and Normal plot of the standardized effects for sound absorption coefficient which indicate that the kapok fibre proportion in the blend, has a highest significant effect on the sound absorption coefficient, carded web mass and stroke frequency shows a second-largest impact on the sound absorption coefficient of the kapok fibre which is followed by frequency and needle depth, and the interaction between carded web mass and carded web mass, stroke frequency and stroke frequency, needle depth and needle depth, and kapok fibre blend% and kapok fibre blend%, which also influence the sound absorption properties, but their influence is less on the sound absorption coefficient of the nonwoven fabric compare to kapok fibre blend%, carded web mass and stroke frequency.

5.1.1.8 Regression Analysis: Kapok fibre nonwoven fabric

The regression analysis of sound absorption coefficient (α) versus kapok fibre blend%, carded web mass, stroke frequency and needle depth without considering the interactive effect of selected parameters at a various frequency discussed below. The regression equation of NAC (α) versus kapok fibre blend%, carded web mass, stroke frequency, needle depth and its interactive effect at a various frequency given in Appendix III (Table 1).

By multiple regression analysis, the coefficient of different parameters and their probability value p-value at a 95% confidence interval were calculated with the help of Minitab 18 software, and results are shown in Table 5.3.

Table 5.3: Estimated regression coefficient and corresponding p-value for kapok fibre nonwoven fabric

Term	**Coef**	**SE Coef**	***P*-Value**
Constant	-0.4668	0.0274	<0.001
X_1	0.005847	0.000291	<0.001
X_2	0.000341	0.000029	<0.001
X_3	0.000451	0.000058	<0.001
X_4	0.00494	0.00116	<0.001

Term	Coef	SE Coef	*P*-Value
X_5			
250	0	0	*
500	0.0558	0.0108	<0.001
1000	0.1348	0.0108	<0.001
2000	0.3106	0.0108	<0.001
2500	0.3884	0.0108	<0.001
3150	0.5203	0.0108	<0.001
4000	0.5948	0.0108	<0.001
5000	0.6326	0.0108	<0.001
6300	0.679	0.0108	<0.001

Following equation indicate the regression equation of NAC (α) versus kapok fibre blend%, carded web mass, stroke frequency and needle depth without considering its interactive effect at a various frequency.

Regression equation of sound absorption coefficient for kapok fibre nonwoven fabric

$$\begin{aligned} NAC(\alpha) = & -0.4668 + 0.005847X_1 + 0.000341X_2 + 0.000451X_3 + 0.00494X_4 \\ & + 0.0X_5(250Hz) + 0.0558X_5(500Hz) + 0.1348X_5(1000Hz) \\ & + 0.3106X_5(2000Hz) + 0.3884X_5(2500Hz) + 0.5203X_5(3150Hz) \\ & + 0.5948X_5(4000Hz) + 0.6326X_5(5000Hz) + 0.6790X_5(6300Hz) \end{aligned} \tag{5.1}$$

From the obtained coefficient value of the parameters, it can be said that sound wave frequency and fibre proportion in the blend played a dominant role among all the selected parameters, which also observed from the Pareto chart. The carded web mass, stroke frequency and needle depth show the significant influence on the sound absorption coefficient of the kapok fibre nonwoven fabric.

The regression equation of NAC (α) versus kapok fibre blend%, carded web mass, stroke frequency, needle depth and its interactive effect at a various frequencies are given in Appendix III. Following regression equation indicate the Noise absorption coefficient (α) versus kapok fibre blend%, carded web mass, stroke frequency, needle depth and its interactive effect at frequency 6300 Hz.

Frequency 6300 Hz

$$\begin{aligned} NAC(\alpha) = & -0.833 + 0.01545X_1 \ + 0.002202X_2 + \ 0.002829X_3 + 0.0391X_4 \\ & - \ 0.000088X_1 * X_1 - \ 0.000002X_2 * X_2 - \ 0.000006X_3 * X_3 \\ & - \ 0.002273X_4 * X_4 - \ 0.000008X_1 * X_2 + \ 0.000007X_1 * X_3 \\ & + \ 0.000064X_1 * X_4 - \ 0.000000X_2 * X_3 + \ 0.000004X_2 * X_3 \\ & + \ 0.000026X_3 * X_4 \end{aligned} \tag{5.2}$$

It was observed that the best sound absorption coefficient value achieved at sound wave frequency 6300 Hz. From the above equation and Appendix III (Table 1) for the obtained coefficient value of the parameters, it can be said that fibre proportion in the blend played a dominant role among all the selected parameters, which also observed from the Pareto chart. The carded web mass and stroke frequency show the second-largest impact on the sound absorption coefficient of the kapok fibre nonwoven fabric. The sound frequency shows the third influencing parameters. The interaction between needle depth and sound frequency played the least impactful role in determining the sound absorption coefficient. The response surface methodology was used to evaluate the effect of different parameters and their interactive effect on the sound absorption coefficient. It is observed that all the selected parameters show a significant influence on the sound absorption coefficient of kapok fibre nonwoven fabric. Other regression equations with interactive effect at various frequencies are given in Appendix III (Table 1).

Statistic analysis for optimization of sound absorption coefficient indicates that the highest value of the sound absorption can be achieved with blend% 70, carded web mass g/m^2 479, stroke frequency 295, and needle depth 12 mm at 6300 Hz frequency. Table 5.4 and figure 5.9 indicate the response optimization for sound absorption coefficient value which can be used to get the best possible value of sound absorption coefficient.

Table 5.4: Multiple response prediction: NAC(α)

Variable	**Setting**
Kapok Fibre Blend (%)	70
Carded Web Mass (g/m^2)	478.788
Stroke Frequency (/min)	295.455
Needle Depth (mm)	11.6667

Frequency (Hz)	6300
Response	**NAC** (α)
Fit	0.9562
SE Fit	0.0209

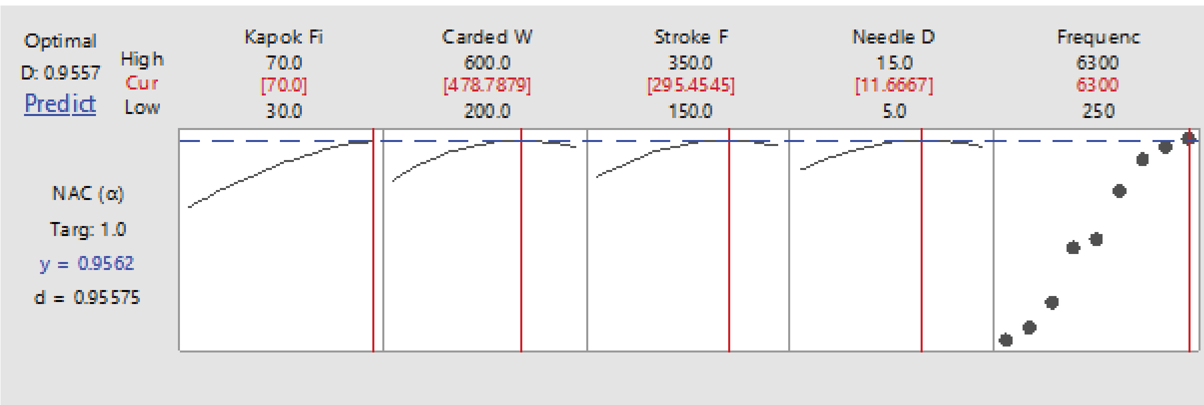

Figure 5.9: Optimization plot of kapok fibre nonwoven fabric

5.1.2 Effect of proportion of kapok fibre in the blend on the sound absorption coefficient

Table 5.5: Average sound absorption coefficient value of samples with different proportion of kapok fibre in the blend at different frequency

Sr. No	Blend % (Kapok / Modal)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	**500 Hz**	**1000 Hz**	**2000 Hz**	**2500 Hz**	**3150 Hz**	**4000 Hz**	**5000 Hz**	**6300 Hz**
1	30/70	0.02	0.05	0.18	0.36	0.50	0.59	0.62	0.69	0.72
2	40/60	0.03	0.07	0.17	0.35	0.45	0.59	0.62	0.67	0.74
3	50/50	0.15	0.23	0.29	0.48	0.53	0.64	0.75	0.78	0.82
4	60/40	0.17	0.20	0.27	0.43	0.54	0.69	0.76	0.81	0.85
5	70/30	0.27	0.34	0.49	0.57	0.67	0.82	0.85	0.89	0.93

The effect of the proportion of kapok fibre in the blend studied for the sound absorption coefficient of nonwoven needle punch fabrics and obtained results summarized in Appendix I (Table 2). The average value of the obtain results enumerated, kapok fibre blend % wise in Table 5.5. Nonwoven fabric made with 30%, 40%, 50%, 60%,and 70% kapok fibre proportion is blend ratio are studied for sound absorption coefficient (NAC) at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 2500 Hz, 3150 Hz, 4000 Hz, 5000 Hz and 6300 Hz frequency. Results show that the sound absorption coefficient of nonwoven needle punch fabric is in the range of 0.02 to 0.27 measured at 250 Hz frequency. It is observed that for the same frequency as the proportion of kapok fibre in the blend increased from 30% to 70% the sound absorption coefficient (NAC) also increased from 0.02 to 0.27 by 1250%. Similarly, there is an increase in sound absorption coefficient at 250 Hz frequency by 50%, 400%, 13% and 59% as the fibre proportion in the blend increase from 30% to 40%, 40%to 50%, 50% to 60% and 60% to 70% respectively. From the results, it can be seen that the sound absorption of nonwoven fabric at 500 Hz frequency varied from 0.05 to 0.34 by about 580%. Here the sound absorption coefficient increase by 40%, 229% and 70% as the proportion of the kapok fibre in the blend increase from 30% to 40%, 40%to 50%, and 60% to 70% respectively, except for an increase in the kapok fibre in blend from 50% to 60% there is a 13% decreased in the sound absorption coefficient is observed. The same trend is observed up to frequency 2000 Hz, and then again, it is increased as the fibre proportion in the blend ratio increase for the same frequency. It is observed that for the same fibre proportion in the blend ratio, the sound absorption of the nonwoven fabric increased as the frequency increase from 250 Hz to 6300 Hz. The change in the sound absorption coefficient are in the range of 0.02 to 0.72 by about 3500%, 0.03 to 0.74 by about 2366%, 0.15 to 0.82 by about 447%, 0.17 to 0.85 by about 400%, and 0.27 to 0.93 by about 244% for 30%, 40%, 50%, 60%, and 70% kapok fibre proportion in the blend ratio respectively as the frequency change from 250 Hz to 6300Hz. It has been observed that the sound absorption coefficient of the nonwoven fabric increase with the increase in the fibre proportion in the blend ratio for the same frequency and also increases with the frequency increase from 250 Hz to 6300 Hz for the same fibre proportion in the blend ratio.

It has been observed that the sound absorption coefficient for needle punch nonwoven fabric is generally below 0.5 up to 2000 Hz frequency, and after 2000 Hz frequency, all the results are above 0.5, and the highest value of 0.93 was found at frequency 6300 Hz.

The sound absorption of nonwoven fabric increase with an increase in fibre proportion in the blend ratio and frequency. All Samples show good sound absorption properties above 2000 Hz frequency and gives the highest value at 6300 Hz frequency with a peak value of 0.93 for 70% kapok fibre proportion in the blend ratio.

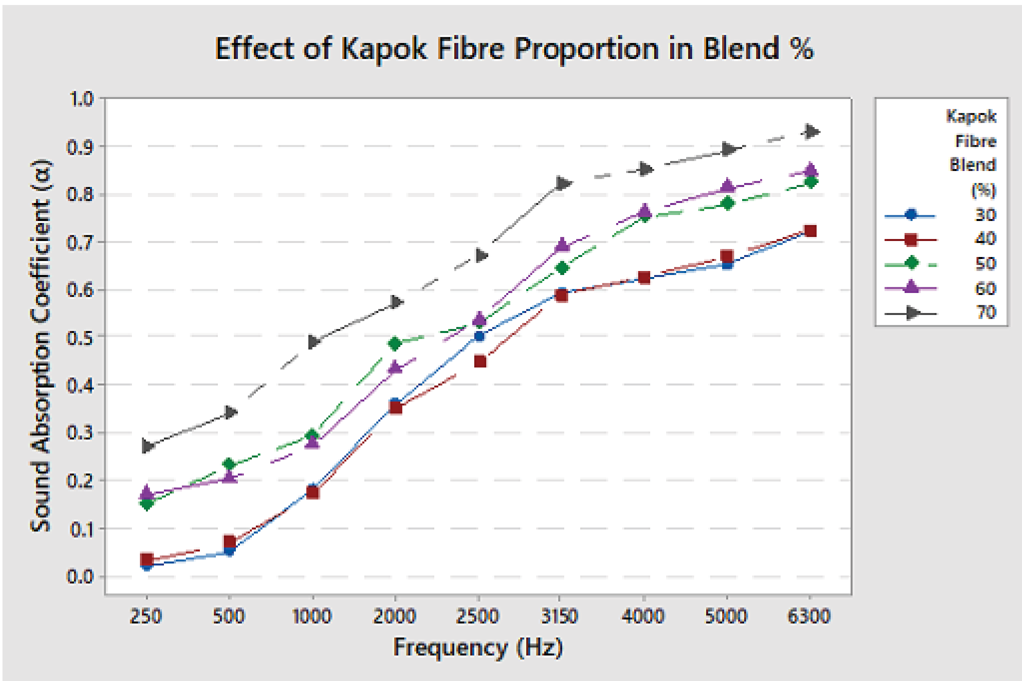

Figure 5.10: Effect of kapok fibre proportion in blend on sound absorption coefficient

It has been found that the sound absorption coefficient of the nonwoven fabric increase with the increase in the kapok fibre proportion in the blend ratio because the natural hollow structure of kapok fibres leads to an increase in the surface area of the fibre. Larger fibre surface area influences the boundaries faced by the sound wave, which in turn leads to an increase in the sound absorption ability of the nonwoven fabric. Narang [176] stated in his research work, increase friction between fibre and air and its effect on sound absorption performance. Hollow fibre due to entrapment of air in their hollow lumen is expected to increase the sound absorption properties of the material by a twofold. Therefore, an increment in the Kapok fibre proportion of the blends leads to more frictional losses and a higher sound absorption coefficient. Figure 5.10 shows the results obtained for a different proportion of kapok fibre in the blend ratio. From the graph, it is clear that a higher proportion of kapok fibre leads to increase sound absorbency of nonwoven fabric and gives the best results at high frequencies.

Previous research work [44], has also stated the importance of fibre diameter and fineness on the sound absorption properties of the material. Kapok fibre due to low density and fineness, a nonwoven fabric made out of kapok fibre has a higher number of fibres, which leads to an increase in the surface area of fibre in fabric and leads to higher sound absorbency. It explains the excellent sound absorption properties of the sample composed of a higher proportion of kapok fibre.

5.1.3 Effect of carded web mass on the sound absorption coefficient

Table 5.6: Average sound absorption coefficient value of samples with different carded web mass at different frequency

Sr. No	Carded web mass (g/m^2)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	500 Hz	1000 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz
1	200	0.01	0.18	0.20	0.29	0.49	0.53	0.65	0.69	0.73
2	300	0.09	0.12	0.20	0.35	0.46	0.61	0.65	0.70	0.74
3	400	0.16	0.23	0.30	0.49	0.54	0.66	0.75	0.78	0.82
4	500	0.12	0.16	0.25	0.44	0.52	0.66	0.74	0.78	0.83
5	600	0.20	0.26	0.34	0.55	0.57	0.69	0.81	0.83	0.89

The effect of carded web mass on the sound absorption coefficient studied and the average value of results depicted in Table 5.6. It has been found that the sound absorption coefficient of nonwoven needle punches fabric increase linearly with an increase in the mass of the carded web. It is observed that the sound absorption coefficient of fabric increase with the increase in the carded wed mass at frequency 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 2500Hz, 3150 Hz, 4000 Hz, 5000 Hz and 6300 Hz. The sound absorption coefficient of the nonwoven fabric is in the range of 0.01 to 0.20 at 250 Hz, 0.18 to 0.26 at 500 Hz, 0.20 to 0.34 at 1000 Hz frequency, which indicates the poor sound absorption of the nonwoven fabric for all samples with different carded web mass. The sound absorption coefficient is in the range of 0.29 to 0.55 at 2000 Hz, the sound absorption coefficient value

0.55 of 600 g/m^2 carded web mass indicates good sound absorption properties of the fabric. The value of the sound absorption coefficient is in the range of 0.49 to 0.57 at 2500 Hz indicate that the nonwoven fabric has good sound absorption properties, particularly for carded web mass 400 to 600 g/m^2. The sound absorption coefficient of all samples with different carded mass is above 0.5 for frequency range 3150 Hz to 6300 Hz. It indicates that the nonwoven fabric samples have excellent sound absorption properties at a higher frequency range. From results, it is also observed that the sound absorption coefficient values are in the range of 0.73 to 0.89 at 6300 Hz frequency for carded web mass 200 to 600 g/m^2. It can be said that the carded web mass 400 to 600 g/m^2 given the highest sound absorption at 3150 Hz to 6300 Hz frequency with a peak at 6300 Hz and 600 g/m^2 carded web mass. The sound absorption coefficient value also linearly increases for the same carded mass as the frequency increase from 250 Hz to 6300 Hz.

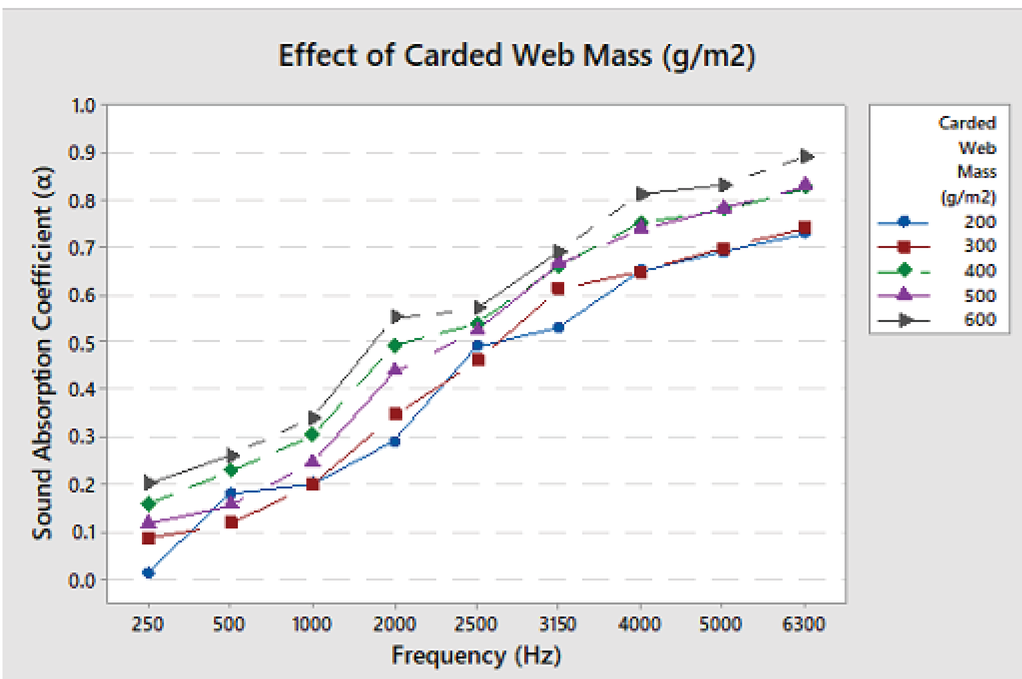

Figure 5.11: Effect of carded web mass on sound absorption coefficient

Figure 5.11 indicate the effect of the carded web mass on the sound absorption coefficient of kapok fibre nonwoven fabric. It also supported by the earlier research work done by Tascan and Vaughn [37]. The increase in the carded web mass leads to an increase in the higher number of fibre within the material, which will increase the air/fibre boundaries within nonwoven needle punch fabric. It will offer higher resistance to the incident sound wave when sound waves interact nonwoven material and lead to an increase in the sound absorption of nonwoven fabric.

5.1.4 Effect of stroke frequency on the sound absorption coefficient

Table 5.7: Average sound absorption coefficient value of samples with different stroke frequency at different sound frequency

Sr. No	Stroke frequency (/min)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	500 Hz	1000 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz
1	150	0.01	0.20	0.19	0.37	0.50	0.61	0.72	0.74	0.78
2	200	0.09	0.12	0.20	0.35	0.47	0.62	0.67	0.71	0.77
3	250	0.16	0.23	0.30	0.49	0.54	0.65	0.75	0.78	0.82
4	300	0.12	0.15	0.24	0.43	0.51	0.66	0.72	0.77	0.80
5	350	0.19	0.25	0.34	0.53	0.55	0.67	0.78	0.80	0.85

The effect of stroke frequency on sound absorption has studied, and the average results depicted in Table 5.7. The sound absorption coefficient is in the range of 0.01 to 0.19, 0.20 to 0.25, and 0.19 to 0.34 at frequencies of 250 Hz, 500 Hz, and 1000 Hz. It is observed that the sound absorption coefficient value increase with the increase in the stoke frequency from 150 /min to 350 /min at a frequency of 250 Hz to 6300 Hz. However, the value of the sound absorption coefficient value below 0.5 indicates the poor sound absorption of nonwoven fabric. So that from results, it can be said that kapok fibre nonwoven fabric has poor sound absorption properties at a frequency range 250 Hz to 2000 Hz except at stroke frequency 350 /min, nonwoven fabric has sound absorption coefficient value 0.53 at 2000 Hz frequency. The value of the sound absorption coefficient is above 0.5 for frequency 2500 Hz to 6300 Hz. Sound absorption value indicates that the kapok fibre nonwoven fabric provides very good sound absorption properties above 2500 Hz frequency. It is also observed that for stroke frequency 150/min, 200 /min, 250/min, 300/min, and 350/min peak value of sound absorption coefficient 0.78, 0.77, 0.82, 0.80, and 0.85 achieved respectively at 6300 Hz frequency. Increase the stroke frequency of needle punch loom from 150 /min to 350 /min leads to an increase in the sound absorption coefficient value and gives the best performance above 2500 Hz frequency with a peak value at 6300 Hz frequency.

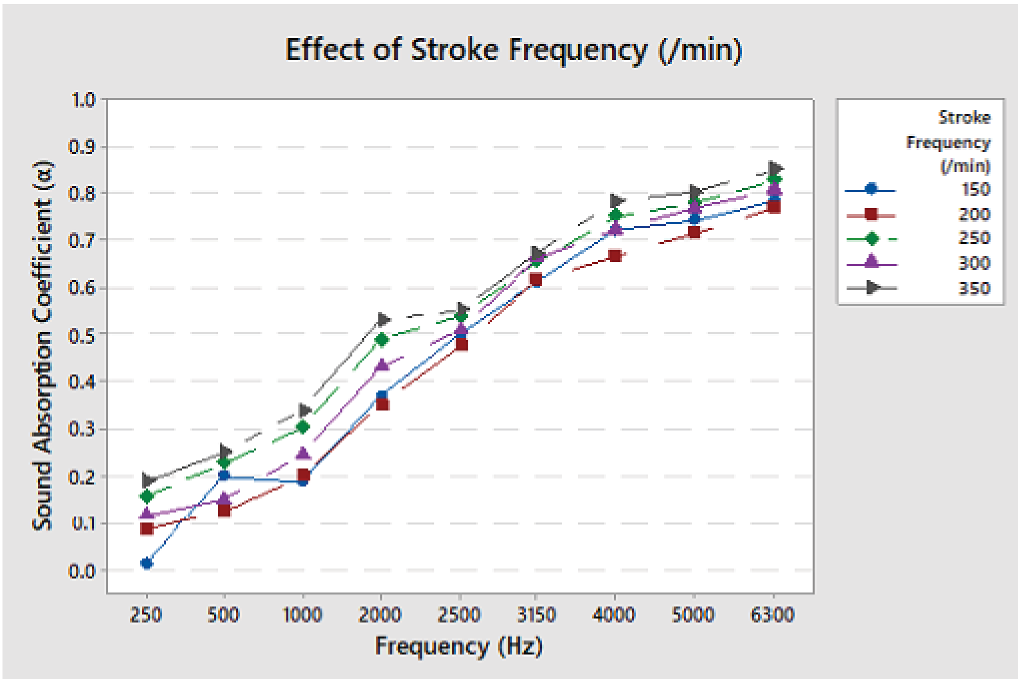

Figure 5.12: Effect of stroke frequency on sound absorption coefficient

Figure 5.12 depicts the effect of the stroke frequency of the sound absorption coefficient on kapok. It shows almost linear increasing trends of the sound absorption coefficient of nonwoven needle punched samples with an increase in stroke frequency. Arrangement of fibre in the structure plays a vital role to increase the fibre to fibre contact within the nonwoven structure. Interaction of incident sound wave depends on the number of fibre to the fibre contact point within the nonwoven structure. An increase in stroke frequency can lead to creating smaller pores in the nonwoven fabric. Increase the stroke frequency in the range of 150-350/min, leads to an increase in several pores which entrap the sound waves in the structure. It will help to increase the sound absorption properties of the material. From the figure, it is clear that the sound absorption coefficient of kapok fibre nonwoven fabrics increased with increased stroke frequency for the same frequency.

5.1.5 Effect of needle depth on the sound absorption coefficient

Table 5.8: Average sound absorption coefficient value of samples with different needle depth at different sound frequency

Sr. No	Needle depth (mm)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	500 Hz	1000 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz
1	5.00	0.15	0.20	0.27	0.40	0.51	0.57	0.69	0.73	0.75
2	7.50	0.09	0.13	0.22	0.38	0.48	0.62	0.68	0.73	0.78
3	10.00	0.15	0.23	0.30	0.49	0.54	0.66	0.75	0.78	0.83
4	12.50	0.11	0.14	0.23	0.40	0.50	0.65	0.71	0.75	0.79
5	15.00	0.18	0.24	0.33	0.51	0.53	0.68	0.75	0.80	0.84

The effect of needle depth on the sound absorption coefficient has studied, and the average of the obtained results depicted in Table 5.8. It is observed that when needle depth increase from 5 mm to 7.5 mm, there is no improvement found in the sound absorption coefficient value except at 3150 Hz and 6300 Hz. Sound absorption coefficient value in the range of 0.15 to 0.18, 0.20 to 0.24, 0.27 to 0.33 and 0.40 to 0.51 for the frequency of 250 Hz, 500 Hz, 1000 Hz and 2000 Hz respectively, shows an increase in the sound absorption coefficient with the increase the needle depth, but expect one value all values of sound absorption coefficient in these frequency range is below 0.5. It indicates the poor performance of the kapok fibre nonwoven fabric in terms of sound absorption properties in the frequency range 250 Hz to 2000 Hz. In the frequency range, 2500 Hz to 6300 Hz, all the values are above 0.5 and ≥ 0.7 for 4000 Hz to 6300 Hz with peak value 0.84 at 6300 Hz frequency for 15 mm needle depth. Kapok fibre nonwoven fabric has excellent sound absorption properties between frequency range 2500 Hz to 6300 Hz. When needle depth increase from 7.5 to 10 mm the sound absorption coefficient value of samples increases from 0.09 to 0.15 by about 67%, Needle depth change from 7.5 to 12.5 mm sound absorption value increase 0.09 to 0.11 by about 22% and increase in the needle depth from 7.5 to 15 mm the sound absorption coefficient value increase from 0.09 to 0.18 by about 100% at frequency 250 Hz. Similarly when the needle depth value change from 7.5 to 10 mm, 7.5 to 12.5 mm and 7.5 to 15 mm the sound absorption coefficient increase in the range of 29% to 77%, 5% to 8% and 34% to 85% for the frequency 500 Hz to 2000 Hz and 7%

to 13%, 1% to 4% and 8% to 10% for frequency 2500 Hz to 6300 Hz. An increase in the needle depth from 5 to 15 mm lead to an increase in the sound absorption coefficient value by about 12% to 20% for the frequency of 250 Hz to 6300 Hz.

Figure 5.13 shows the results obtained of needle penetration depth on the sound absorption coefficient of kapok fibre nonwoven fabric. The increase of needle depth from 7.5 mm to 12.5 mm and 5 mm to 10 mm leads to an increase in the sound absorption properties of the material. It is found that the change in needle depth from 5 mm to 7.5 mm does not affect the sound absorbency property of the material significantly. However, when the needle penetration depth increases from 7.5 mm to 15 mm, it leads to an increase in the sound insulation properties of the nonwoven material. An increase in the needle depth results in intense fibre entanglement, which results in the formation of numbers of small pores that entrap the sound wave in the structure. It will increase the frictional resistance to sound wave and dissipation of more energy and increase the sound absorption coefficient [176].

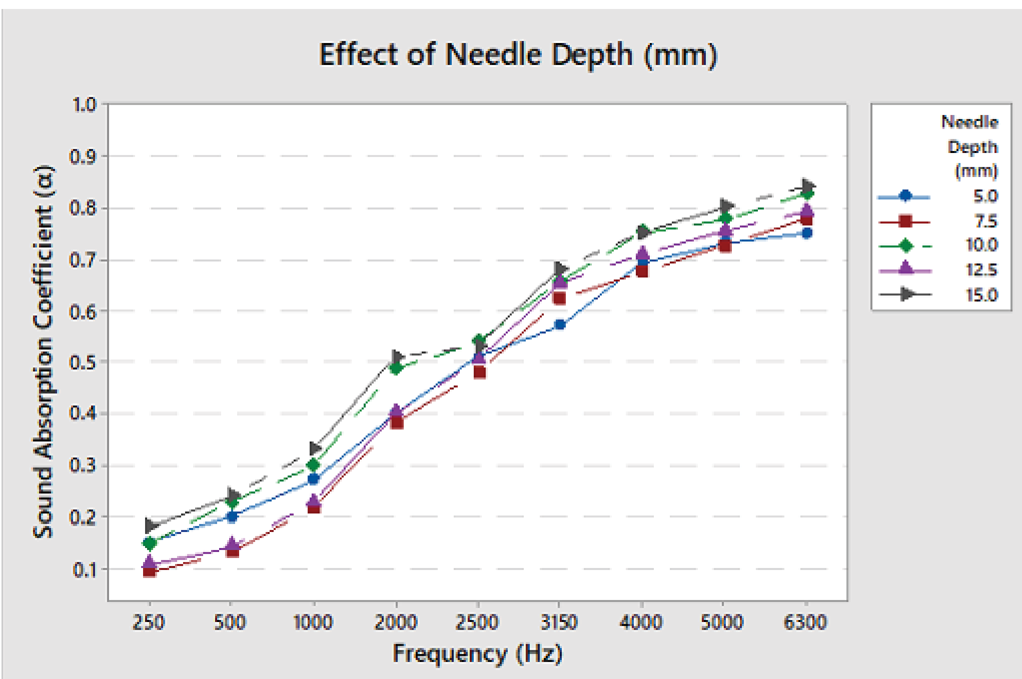

Figure 5.13: Effect of needle depth on sound absorption coefficient

Samples' results indicate that an increase in the proportion of kapok fibres in the blend leads to giving a higher sound absorption coefficient value at a higher frequency. Although the results show an increase in stroke frequency, carded web mass per unit area and needle depth improves the sound absorption coefficient value of the samples. It is found that the sound absorption coefficient increases in direct relation to the increase in carded web mass per unit area (g/m^2) of the samples because it will lead to an increase in tortuosity of the samples and the energy losses due to frictional resistance. Finally, it is observed that all selected parameters give peaks of sound absorption coefficient at a frequency of 6300 Hz.

5.1.6 Effect of fabric thickness on the sound absorption coefficient

Table 5.9: Average sound absorption coefficient value of kapok fibre samples with different fabric thickness at different sound frequency

Sr. No	Fabric thickness (mm)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	500 Hz	1000 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz
1	1.64	0.01	0.18	0.20	0.29	0.49	0.53	0.65	0.69	0.73
2	2.70	0.09	0.12	0.20	0.35	0.46	0.61	0.65	0.70	0.74
3	3.40	0.16	0.23	0.30	0.49	0.54	0.66	0.75	0.78	0.82
4	4.30	0.12	0.16	0.25	0.44	0.52	0.66	0.74	0.78	0.83
5	4.73	0.20	0.26	0.34	0.55	0.57	0.69	0.81	0.83	0.89

The effect of fabric thickness on the sound absorption coefficient observed and the average results depicted in Table 5.9. It indicates that the sound absorption coefficient increased with the increase in the thickness of the fabric at different sound frequencies. The sample having the fabric thickness 1.64 mm shows the sound absorption coefficient values are in the range of 0.01 to 0.73. Samples have a thickness of 2.70 mm, 3.40 mm, 4.30 mm, and 4.73 mm give the sound absorption coefficient value in the range of 0.09 to 0.74, 0.16 to 0.82, 0.12 to 0.83 and 0.20 to 0.89 respectively for the frequency value 250 Hz to 6300 Hz. The peak value of the sound absorption coefficient observed at frequency 6300 Hz for all thickness values of the samples. In the frequency range, 250 Hz to 2000 Hz except one reading all the values of sound absorption coefficients are below 0.5 values for all fabric thickness value, which indicates the poor performance of the nonwoven fabric in terms of the sound absorption coefficient. The sound absorption value is higher than 0.5 for frequency 2500 Hz to 6300 Hz indicate nonwoven fabric with excellent sound absorption properties. At 6300 Hz frequency, the sound absorption value change from 0.73 to 0.89 by about 22% as the fabric thickness increase from 1.64 mm to 4.73 mm.

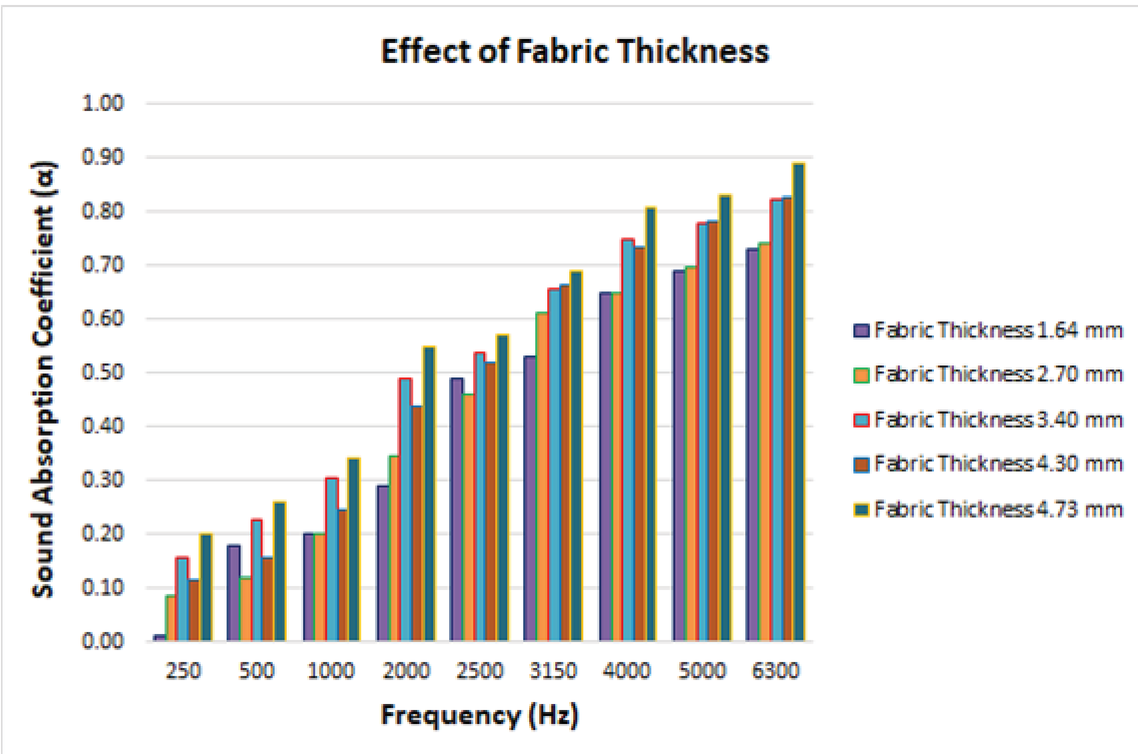

Figure 5.14: Effect of kapok fibre fabric thickness on sound absorption coefficient

Figure 5.14 shows the sound absorption of fabric having a different thickness between frequency bands 250 Hz to 6300 Hz. From the graph, it can be said that up to 2000 Hz frequency value sound absorption coefficient increase with the increase in the fabric thickness but indicates the poor performance of fabric in terms of sound absorption. In the frequency range, 2500 Hz to 6300 Hz, the sound absorption coefficient increase with the increase in the fabric thickness and gives excellent sound absorption properties. The highest sound absorption values observed with 4.73 thickness of fabric at all frequencies, and the peak value is observed at 6300 Hz frequency with 0.89 sound absorption value.

5.1.7 Effect of fabric GSM on the sound absorption coefficient

Table 5.10: Average sound absorption coefficient value of samples with different kapok fabric GSM at different sound frequency

Sr. No	Fabric GSM (g/m^2)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	500 Hz	1000 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz
1	151	0.01	0.18	0.20	0.29	0.49	0.53	0.65	0.69	0.73
2	282	0.09	0.12	0.20	0.35	0.46	0.61	0.65	0.70	0.74
3	340	0.16	0.23	0.30	0.49	0.54	0.66	0.75	0.78	0.82
4	469	0.12	0.16	0.25	0.44	0.52	0.66	0.74	0.78	0.83
5	542	0.20	0.26	0.34	0.55	0.57	0.69	0.81	0.83	0.89

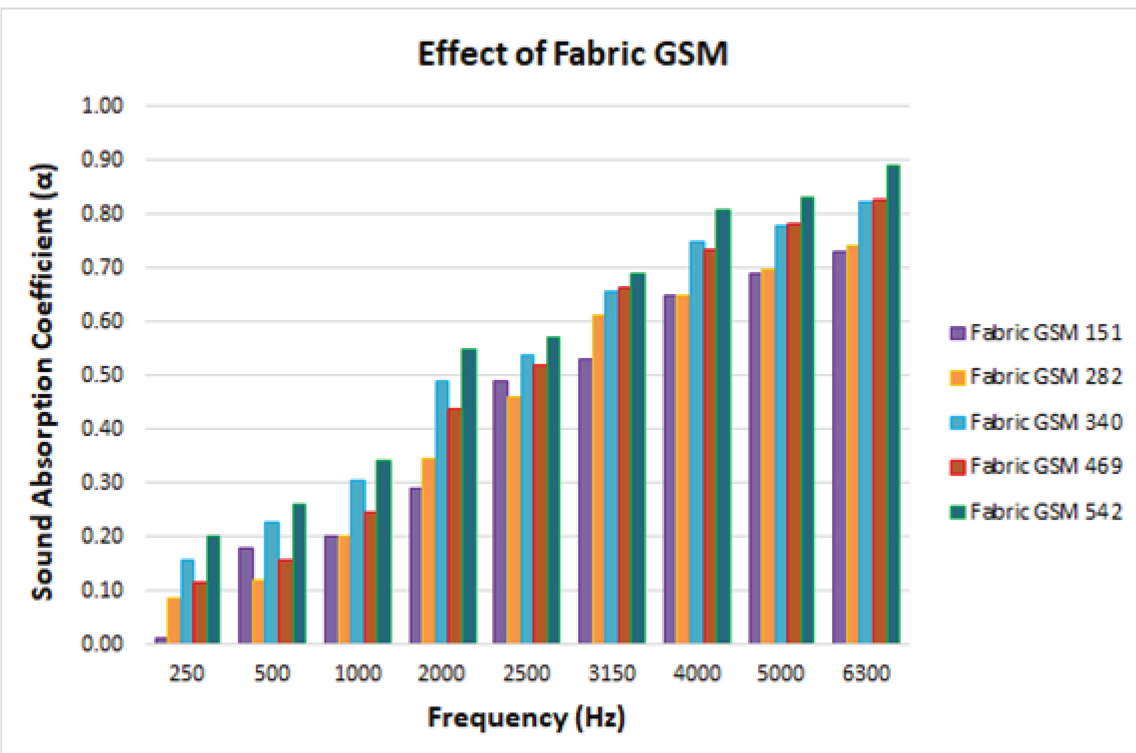

Figure 5.15: Effect of kapok fibre fabric GSM on sound absorption coefficient

The effect of fabric GSM on the sound absorption coefficient studied and the averaged results depicted in Table 5.10. It is observed that the sound absorption coefficient increase with an increase in the fabric GSM with frequency. Fabric with 151 g/m^2 gives the lowest sound absorption coefficient value 0.01 at 250 Hz, and fabric with 542 g/m^2 gives the highest value 0.89 at 6300 Hz. Higher fabric GSM value means more number of fibres within the nonwoven fabric structure, which lead to increase fibre/air boundaries. Increased in the fibre/air boundaries of nonwoven fabric will offer a higher resistance to the incident sound wave and leads to an increase in the sound absorption property of the materials. Figure 5.15 shows the sound absorption coefficient of nonwoven fabric at a different frequency for a fabric having different GSM values. Sound absorption value increases with increased frequency from 250 Hz to 6300 Hz for a fabric having different GSM. The graph indicates the nonwoven fabric has better sound absorbency properties at a frequency of 2500 Hz to 6300 Hz. In this frequency range, all the sound absorption values are higher than 0.5. Fabric having 542 g/m^2 gives a higher value at each frequency and highest value at 6300 Hz frequency.

5.1.8 Effect of fabric air permeability on the sound absorption coefficient

Table 5.11: Average sound absorption coefficient of kapok fabric with different air permeability at different frequency

Sr. No	**Air permeability (m^3/m^2 /hr) at 100 Pa**	**Sound absorption coefficient value (α) at different frequency**								
		250 Hz	**500 Hz**	**1000 Hz**	**2000 Hz**	**2500 Hz**	**3150 Hz**	**4000 Hz**	**5000 Hz**	**6300 Hz**
1	910	0.01	0.18	0.20	0.29	0.49	0.53	0.65	0.69	0.73
2	491	0.09	0.12	0.20	0.35	0.46	0.61	0.65	0.70	0.74
3	392	0.16	0.23	0.30	0.49	0.54	0.66	0.75	0.78	0.82
4	276	0.12	0.16	0.25	0.44	0.52	0.66	0.74	0.78	0.83
5	222	0.20	0.26	0.34	0.55	0.57	0.69	0.81	0.83	0.89

The effect of fabric air permeability on the sound absorption coefficient studied and the averaged results depicted in Table 5.11. It is observed that the sound absorption coefficient of the nonwoven fabric sample shows the inverse relation between sound absorption coefficient and air permeability, which means lower air permeability of nonwoven fabric exhibits better sound absorption performance. Thus, there is some indirect relation between the sound absorption coefficient of nonwoven fabric and air permeability. It is observed that the air permeability of kapok fibre nonwoven fabric decrease with increasing fabric thickness and fabric GSM. Nonwoven fabric with a higher value of fabric thickness and fabric GSM has less porosity and air space in the nonwoven fabric structure, which leads to provide higher resistance to air and result in less air permeability. Here, the sound absorption coefficient of the nonwoven fabric increase with the reduction of air permeability. The sample has air permeability value 910 m^3/m^2/hr gives the lowest sound absorption coefficient value 0.01 at frequency 250 Hz and a sample having the air permeability value 222 m^3/m^2/hr gives the highest sound absorption coefficient value 0.89 at frequency 6300 Hz. The sample having air permeability value 222 m^3/m^2/hr gives higher sound absorption coefficient value at each frequency with peak value 0.89 at 6300 Hz.

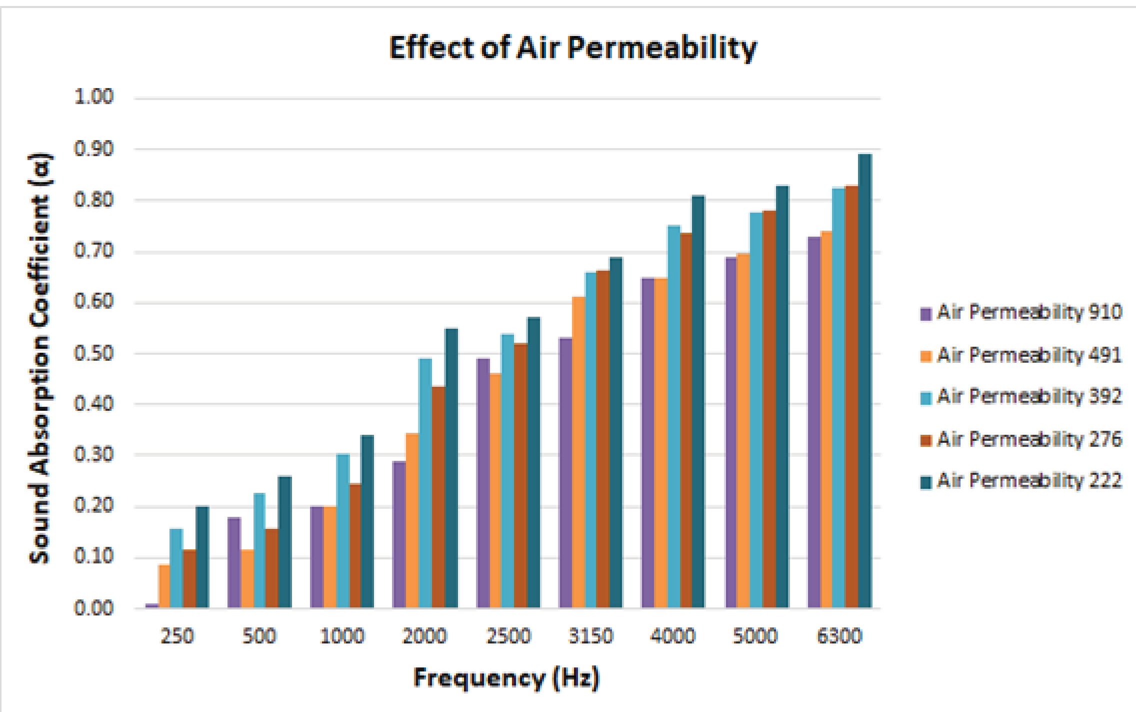

Figure 5.16: Effect of kapok fibre fabric air permeability on sound absorption coefficient

Figure 5.16 shows that all sample gives the sound absorption value below 0.5 up to 2000 Hz frequency which indicates the poor sound absorption properties of all samples, and at frequency 2500 Hz to 6300 Hz sample having different air permeability shows excellent sound absorbency. It is observed that the sound absorption coefficient increase with an increase in frequency value with a fixed air permeability value of nonwoven fabric samples. Results show that the sound absorption coefficient value increased as the air permeability value of nonwoven fabric decreased for a fixed frequency value.

5.1.9 Effect of fabric porosity on the sound absorption coefficient

Table 5.12: Average sound absorption coefficient of kapok fabric with different porosity at different frequency

Sr. No	Fabric porosity (%)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	**500 Hz**	**1000 Hz**	**2000 Hz**	**2500 Hz**	**3150 Hz**	**4000 Hz**	**5000 Hz**	**6300 Hz**
1	89.82	0.01	0.18	0.20	0.29	0.49	0.53	0.65	0.69	0.73
2	88.18	0.09	0.12	0.20	0.35	0.46	0.61	0.65	0.70	0.74
3	88.75	0.16	0.23	0.30	0.49	0.54	0.66	0.75	0.78	0.82
4	87.61	0.12	0.16	0.25	0.44	0.52	0.66	0.74	0.78	0.83
5	87.35	0.20	0.26	0.34	0.55	0.57	0.69	0.81	0.83	0.89

The effect of fabric porosity on the sound absorption coefficient studied and the averaged results depicted in Table 5.12. It is observed that the sound absorption coefficient of kapok fibre nonwoven fabric shows similar trends for fabric porosity and air permeability, and it obvious that the increase in the fabric air permeability leads to an increase in porosity of the nonwoven fabric. It is observed that the porosity of kapok fibre nonwoven fabric decrease with the increasing fabric thickness and fabric GSM because nonwoven fabric with a higher value of fabric thickness and fabric GSM have less air space in the nonwoven fabric structure. Results indicate that the porosity of the fabric affects the value of the sound absorption coefficient. The sound absorption coefficient value of the fabric sample increased with a decrease in the porosity of the fabric. Sample with porosity value 87.35 gives higher sound absorption coefficient value at a frequency of 250 Hz to 6300 Hz, and the highest value of sound absorption coefficient at 6300 Hz frequency as shown in figure 5.17.

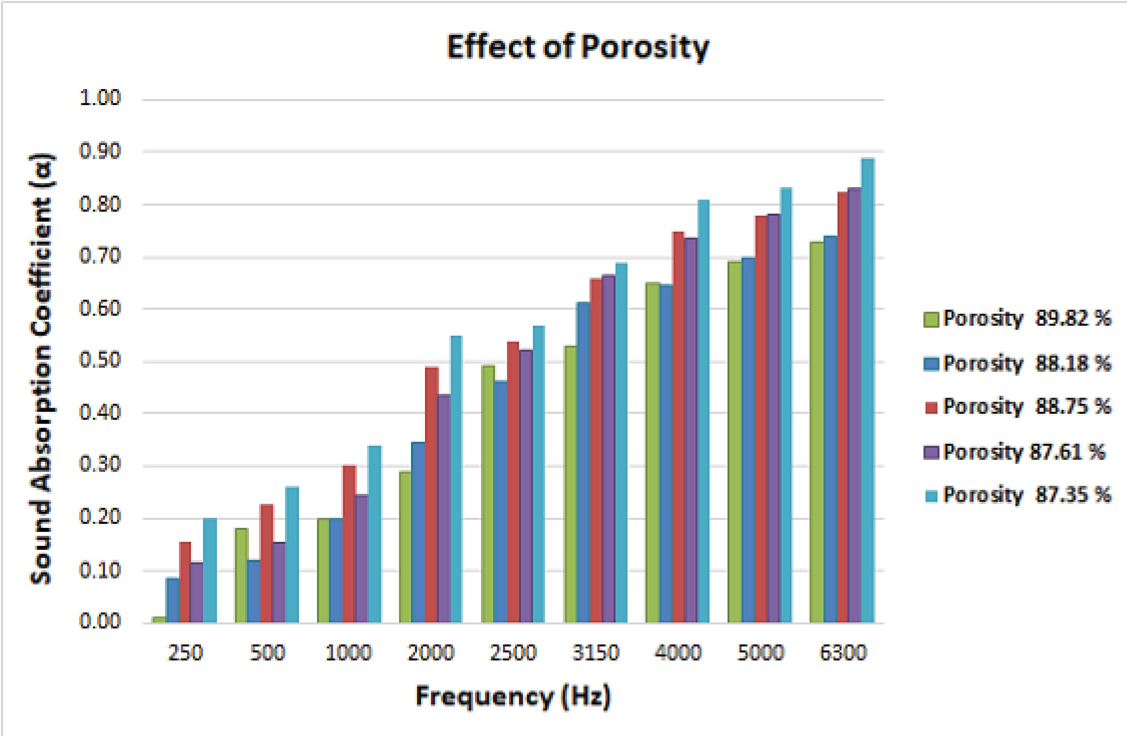

Figure 5.17: Effect of kapok fabric porosity on sound absorption coefficient

5.1.10 Interactive effect of different physical properties on the sound absorption coefficient

Kapok fibre nonwoven fabric physical properties like fabric GSM, fabric thickness, and air permeability measured in standard testing conditions. Fabric density and porosity also calculated using fabric and fibre data. The sound absorption coefficient of nonwoven fabric measured at different frequency levels. Four readings of sound absorption coefficient were taken for each sample, and the average value of the obtained results along with the physical properties of fabric depicted in the Appendix II (Table 1). Here, the corresponding coded variables of fabric GSM, fabric thickness, air permeability, porosity and sound wave frequency respectively given in Table 5.13.

Table 5.13: Coded variable for physical properties of kapok fibre fabric

Variables	Coded variables
Fabric GSM	A
Fabric Thickness (mm)	B
Air Permeability (m^3/m^2/hr)	C
Porosity (%)	D
Frequency (Hz)	E

Analysis of variance and regression analysis is used to analyze the effect of various physical parameters of kapok fabric and its interactive effect on the sound absorption coefficient.

Table 5.14: ANOVA regression model of kapok fabric physical properties for the sound absorption coefficient

Source	**Degree of freedom (DF)**	**Sum of squares (SS)**	**Mean of squares (MS)**	***F* Value**	***P* Value**
Model	54	17.6244	0.326378	147.19	<0.001
Linear	12	3.733	0.311082	140.3	<0.001
A	1	0.0038	0.00383	1.73	0.19
B	1	0.0578	0.057842	26.09	<0.001
C	1	0.0512	0.05125	23.11	<0.001
D	1	0.1154	0.115422	52.05	<0.001
E	8	3.4902	0.436278	196.76	<0.001
Square	4	0.1316	0.032889	14.83	<0.001
A^2	1	0.0234	0.023442	10.57	0.001
B^2	1	0.0474	0.047435	21.39	<0.001
C^2	1	0.0461	0.046088	20.79	<0.001
D^2	1	0.0591	0.059104	26.66	<0.001
2-Way Interaction	38	0.1195	0.003144	1.42	0.064
A * B	1	0.0325	0.032542	14.68	<0.001

Source	Degree of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	***F*** **Value**	***P*** **Value**
A * C	1	0.0139	0.013935	6.28	0.013
A * D	1	0.0367	0.036685	16.54	<0.001
A * E	8	0.0045	0.000562	0.25	0.98
B * C	1	0.0023	0.002341	1.06	0.305
B * D	1	0.0467	0.046692	21.06	<0.001
B * E	8	0.0034	0.000423	0.19	0.992
C * D	1	0	0.000046	0.02	0.885
C * E	8	0.005	0.000622	0.28	0.972
D * E	8	0.0111	0.001392	0.63	0.754
Error	224	0.4967	0.002217		
Total	278	18.1211			
Model Summary					
Square	:	0.0470886			
R^2	:	97.26%			
R^2 (adj)	:	96.60%			
R^2 (pred)	:	95.58%			

In present study, Minitab 18 software used for statistical data analysis. The effect of the measured physical property of kapok fabric thickness, fabric GSM, air permeability, and porosity on the dependent parameter sound absorption coefficient examined for 31 kapok fibre nonwoven fabric with analysis of variance at a significance level of value p less than 0.05. The model summary and ANOVA analysis of obtained results depicted in Table 5.14.

Analysis of variance (ANOVA) analysis of kapok fibre nonwoven fabric indicates that the kapok fabric thickness, fabric air permeability, porosity, and sound wave frequency significantly influence the sound absorption coefficient of the fabric because their p-value is < 0.001. According to the F values, sound wave frequency, porosity, fabric thickness, and air permeability are more significantly affect the sound absorption coefficient than fabric GSM. It indicates that the increase in the GMS of fabric will not serve the purpose.

Type of the material and fabric structure also play a vital role in the sound absorption properties of the nonwoven fabric.

ANOVA analysis of Square and 2-way interaction shows that interaction between fabric thickness (mm) and fabric thickness (mm), fabric GSM (g/m^2) and fabric GSM (g/m^2), air permeability (m^3/m^2/hr) and air permeability (m^3/m^2/hr), porosity (%) and porosity (%), fabric GSM (g/m^2) and fabric thickness (mm), fabric GSM (g/m^2) and porosity (%), fabric thickness (mm) and porosity (%), fabric GSM (g/m^2) and air permeability (m^3/m^2/hr) significantly influence the sound absorption coefficient of the kapok fibre nonwoven fabric. According to the F value, the interaction between the porosity (%) and porosity (%), fabric thickness (mm) and fabric thickness (mm), fabric thickness (mm) and porosity (%), air permeability (m^3/m^2/hr) and air permeability (m^3/m^2/hr), fabric GSM (g/m^2) and porosity(%), fabric GSM (g/m^2) and fabric thickness (mm), fabric GSM (g/m^2) and fabric GSM (g/m^2), fabric GSM (g/m^2) and air permeability (m^3/m^2/hr) influences the sound absorption coefficient. Statistical analysis at p-value 0.05 indicates that interaction between fabric GSM (g/m^2) and frequency (Hz), fabric thickness (mm) and frequency (Hz), air permeability (m^3/m^2/hr) and frequency (Hz), air permeability (m^3/m^2/hr) and porosity, porosity (%) and frequency (Hz), fabric thickness (mm) and air permeability (m^3/m^2/hr) have less influence on the sound absorption coefficient of kapok fibre nonwoven fabric.

The coefficient of determination R^2 value is 97.26%, which indicates that the sound absorption coefficient of kapok fibre nonwoven fabric is affected by fabric thickness, air permeability, porosity, fabric GSM and sound frequency with confidence level 97.26%. The model predicts the sound absorption coefficient successfully at a level of 95.58%. The p-value < 0.001 indicates the model is statistically highly significant.

5.1.10.1 Regression Analysis: physical properties of kapok fibre nonwoven fabric

The regression analysis of sound absorption coefficient (α) versus kapok fabric GSM, fabric thickness, air permeability and porosity without considering interactive effect of selected parameters at a various frequency discussed below. The regression equation of NAC (α) versus kapok fabric GSM, fabric thickness, air permeability, porosity, and its interactive effect at a various frequency given in Appendix III (Table 2).

By multiple regression analysis, the coefficient of different physical properties and their probability value p-value at a 95% confidence interval were calculated with the help of Minitab 18 software, and results are shown in Table 5.15.

Table 5.15: Regression Analysis: physical properties of kapok fibre nonwoven fabric

Term	**Coef**	**SE Coef**	***P*-Value**
Constant	0.4637	0.0453	<0.001
A	0.000313	0.000131	0.017
B	0.0368	0.0144	0.011
C	0.000253	0.000045	<0.001
D	0.00367	0.00138	0.008
E			
250	0	0	*
500	-0.6232	0.0175	<0.001
1000	-0.5442	0.0175	<0.001
2000	-0.3684	0.0175	<0.001
2500	-0.2906	0.0175	<0.001
3150	-0.1587	0.0175	<0.001
4000	-0.0842	0.0175	<0.001
5000	-0.0465	0.0175	0.009
6300	-0.679	0.0175	<0.001

The following equation shows the Regression Analysis of sound absorption coefficient (α) versus kapok fabric GSM, fabric thickness, air permeability and porosity without considering their interactive effect at different frequency level.

$$\begin{aligned} NAC(\alpha) = {} & 0.4637 + 0.000313A + 0.0368B + 0.000253C + 0.00367D - 0.0E(250Hz) \\ & - 0.6232E(500Hz) - 0.5442E(1000Hz) - 0.3684E(2000Hz) \\ & - 0.2906E(2500Hz) - 0.1587E(3150Hz) - 0.0842E(4000Hz) \\ & - 0.0465E(5000Hz) + 0.6790E(6300Hz) \end{aligned} \tag{5.3}$$

From the obtained coefficient value of the parameters, it can be said that fabric thickness and porosity played a dominant role among all the selected parameters. The fabric

GSM and air permeability show the second-largest impact on the sound absorption coefficient of the kapok fibre nonwoven fabric.

The regression equation of NAC (α) versus kapok fabric GSM, fabric thickness, air permeability, porosity, and its interactive effect at different frequency level are given in Appendix III. Following regression equation indicate the sound absorption coefficient (α) versus kapok fabric GSM, fabric thickness, air permeability, porosity, and its interactive effect at frequency 6300 Hz.

$$
\begin{aligned}
NAC(\alpha) = & -76.8 + 0.0708A - 8.97B - 0.00574C + 1.877D - 0.000024A*A \\
& - 0.3484B*B + 0.000003C*C - 0.01109D*D + 0.00614A*B \\
& + 0.000006A*C - 0.000874A*D + 0.000288B*C + 0.1040B*D \\
& + 0.000006C*D
\end{aligned} \tag{5.4}
$$

It was observed that the best sound absorption coefficient value achieved at sound wave frequency 6300 Hz. From the above equation and Appendix III (Table 2) for the obtained coefficient value of the parameters, it can be said that thickness and porosity played a dominant role among all the selected parameters, which also observed from the Pareto chart. The air permeability also show impact on the sound absorption coefficient of the kapok fibre nonwoven fabric. The sound frequency shows their considerable influence on the sound absorption coefficient values and the highest results was obtained at frequency 6300 Hz. It is observed that among all the selected parameters fabric GSM show insignificant influence on the sound absorption coefficient of kapok fibre nonwoven fabric. It indicates that the increase in the GMS of fabric will not serve the purpose. Type of the material and fabric structure also play a vital role in the sound absorption properties of the nonwoven fabric. Other regression equations with interactive effect at various frequencies are given in Appendix III (Table 2).

The Pareto chart and Normal plot of the standardized effects for the sound absorption coefficient in Figure 5.18 and 5.19 shows porosity, and frequency has the highest effect on the sound absorption coefficient than other parameters. Fabric thickness, air permeability and the interaction between porosity and porosity, fabric thickness and fabric thickness, fabric thickness and porosity, air permeability and air permeability, fabric GSM and porosity, fabric GSM and fabric thickness, fabric GSM and fabric GSM, fabric GSM and air permeability have a significant influence on the sound absorption coefficient of the nonwoven fabric. Effect of fabric GSM and the interaction between fabric thickness and air permeability, porosity and frequency, air permeability and porosity, air permeability and frequency, fabric GSM and frequency, fabric thickness and frequency on sound absorption coefficient is very less in compare to fabric thickness, porosity and air permeability.

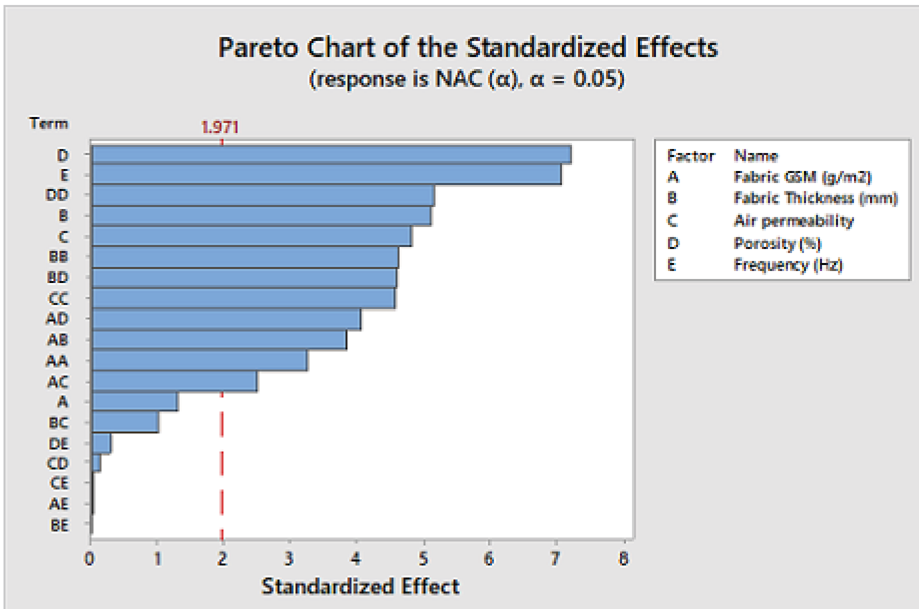

Figure 5.18: Pareto chart for physical properties of kapok fibre nonwoven fabric

Figure 5.19: Normal plot for physical properties of kapok fibre nonwoven fabric

5.2 Estabragh (Milkweed) Fibre

5.2.1 Interactive effect of different process parameters on the sound absorption coefficient

The effect of the process variable viz proportion of milkweed fibre in the blend, carded web mass, stroke frequency and needle depth on the sound absoprtion coefficient of milkweed fibre nonwoven fabric has been taken into consideration by using the response surface methodology based on the central composite design. Design of experiment (DOE) planned using Minitab 18 software according to RSM-CCD methods given in Appendix I. In this design of the experiment, four continuous factors like milkweed fibre proportion in the blend% Y_1, carded web mass g/m^2 Y_2, stroke frequency (/min) Y_3 of needle punch machine, needle depth (mm) Y_4, and one categorical factor sound frequency (Hz) Y_5 are selected. Obtained results of the sound absorption coefficient are fed in the table as a response to carry out the further analysis of data.

In this study, sound absorption coefficient results are analyzed using the response surface method with the help of Minitab 18 software. The average value of obtained results of sound absorption coefficient of the milkweed fibre nonwoven fabric for different variables are enumerated in Appendix – I (Table 4).

5.2.1.1 Interactive effect of milkweed fibre blend% and carded web mass on sound absorption coefficient

The contour plot in Figure 5.20 shows the effects of estabragh (milkweed) fibre blend% and carded web mass (g/m^2) on sound absorption coefficient for certain hold values of stroke frequency, needle depth and frequency. As indicated in Figure 5.20, the proportion of milkweed fibre in the blend% and carded web mass have considerable influence on the sound absorption coefficient at 6300 Hz frequency as all the sound absorption values are above 0.5. The highest values of the sound absorption coefficient are in the upper right corner of the plot, which corresponds with high values of both milkweed fibre blend% and carded web mass (g/m^2). The lowest values of the sound absorption coefficient are in the lower left corner of the plot, which corresponds with low values of milkweed fibre blend% and carded web mass (g/m^2). The lowest value of the sound absorption coefficient was achieved at 30% milkweed fibre proportion in the blend and 200 g/m^2 carded web mass.

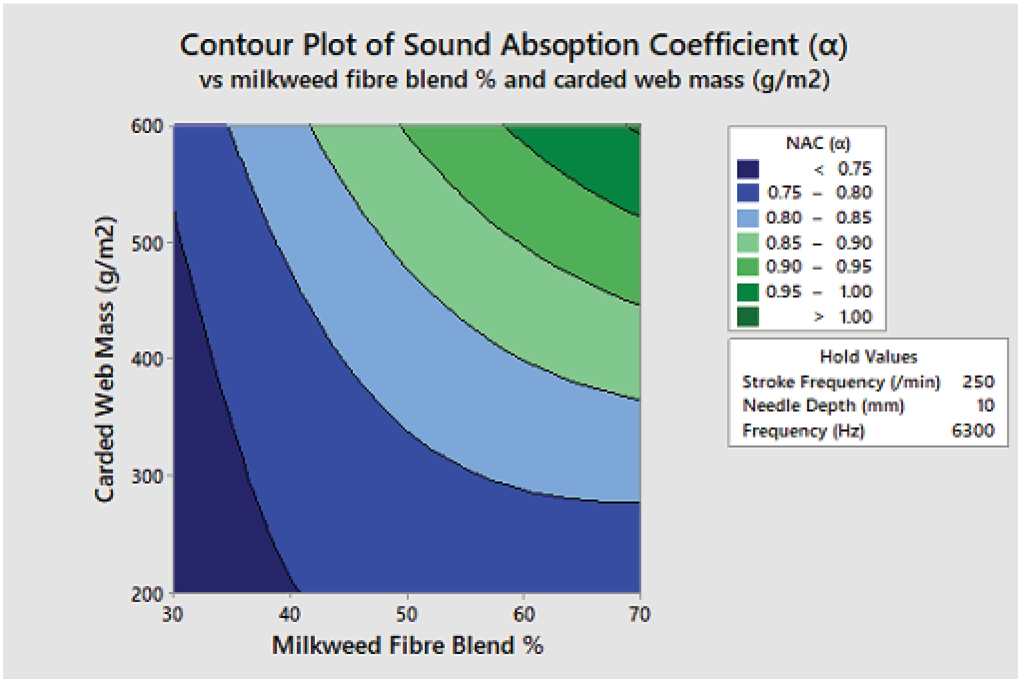

Figure 5.20: Effect of milkweed fibre blend% and carded web mass on sound absorption coefficient

The highest sound absorption value was achieved with 70% proportion of milkweed fibre in the blend and 600 g/m^2 carded web mass. The sound absorption value >0.9 was achieved with milkweed fibre proportion in blend 50 to 70% and carded web mass 450 g/m^2 to 600 g/m^2. It is clear from the graph that as the proportion of milkweed fibre in the blend increased, the sound absorption coefficient also increases. No change in the Sound absorption value was observed for milkweed fibre blend% 41 to 70 and carded web mass 200 to 300 g/m^2. 70% proportion of milkweed fibre in the blend and carded web mass 600 g/m^2 shows sound absorption value 1, which means 100% sound absorption. An increase in the milkweed fibre proportion in the blend, increases the surface area of fibre in the fabric due to the hollow structure of milkweed fibre. Large fibre surface area influences the boundary faced by the sound wave, which helps to increase the sound absorption ability of the milkweed fibre nonwoven fabric. Hollow fibre due to entrapment of air in their hollow lumen is expected to increase the sound absorption property of nonwoven fabric [176]. A nonwoven fabric made out of milkweed fibres has more number of fibre in structure for the same GSM, due to its low density and fineness [44, 80]. Figure 5.20 shows that the sound absorption coefficient value increase with an increase in the carded web mass and the highest value was achieved at 600 g/m^2. It was observed that, when the carded web mas increased from 200 g/m^2 to 280 g/m^2, no improvement in the sound absorption properties. But increase in the carded web mass from 400 g/m^2 to 600 g/m^2 significantly influence the sound absorption properties of milkweed fibre nonwoven fabric. An increase in the carded web mass, increase the number of fibre in the nonwoven fabric structure, so when the sound wave interacts with the nonwoven fabric it offers higher resistance to the incident sound wave due to an increase in the air/fibre boundaries [37, 177] and gives higher sound absorption coefficient values.

5.2.1.2 Interactive effect of milkweed fibre blend% and stroke frequency on sound absorption coefficient

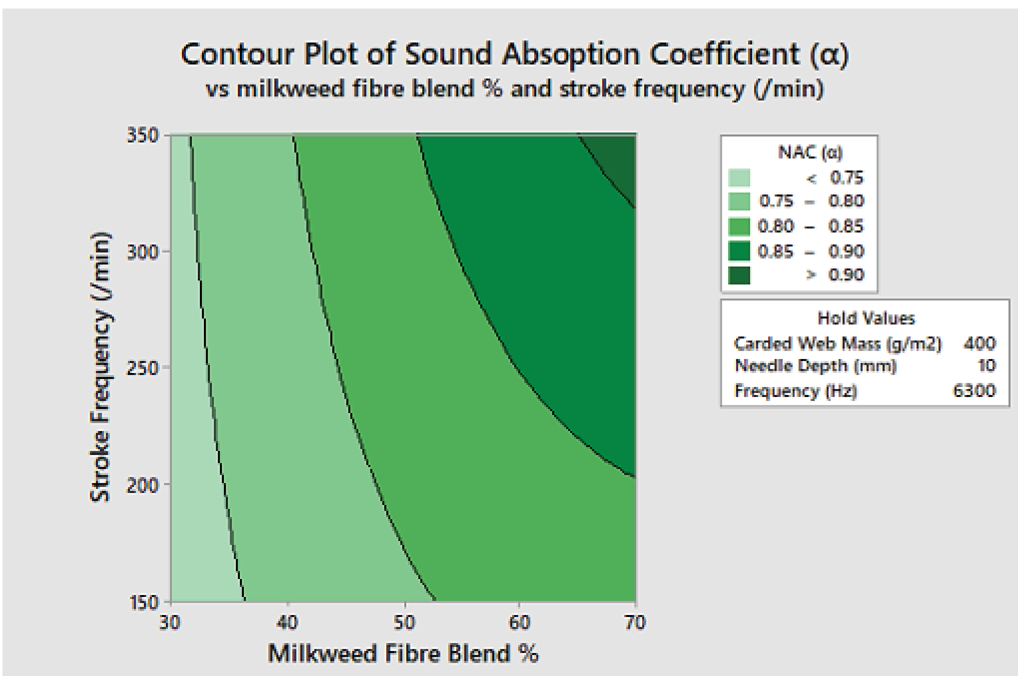

Figure 5.21: Effect of milkweed fibre blend% and stroke frequency on sound absorption coefficient

The contour plot in Figure 5.21 shows the effects of milkweed fibre blend% and stroke frequency on sound absorption coefficient for certain hold values of carded web mass, needle depth and frequency. As shown in Figure 5.21, the proportion of milkweed fibre in the blend% and stroke frequency have considerable influence on the sound absorption coefficient as all the sound absorption values are above 0.5 at 6300 Hz frequency. The highest values of the sound absorption coefficient are in the upper right corner of the plot, which corresponds with high values of both milkweed fibre blend% and stroke frequency (/min). The lowest values of the sound absorption coefficient are in the lower left corner of the plot, which corresponds with low values of milkweed fibre blend% and stroke frequency (/min). The lowest value of the sound absorption coefficient was achieved with a 30% milkweed fibre proportion in the blend and 150 strokes per minute. The highest sound absorption value was achieved for milkweed fibre blend% 70 and 350 strokes per minute. The sound absorption value >0.9 was achieved with 65 to 70% of milkweed fibre proportion in blend and stroke frequency 325/min to 350/min. It is clear from the graph that as the proportion of milkweed fibre in the blend increased the sound absorption coefficient also increase. A nonwoven fabric made of milkweed fibre gives higher sound absorption due to its hollow structure, low density and fineness [44, 80, 176]. Figure 5.21 shows that as the stroke of the nonwoven fabric increase, no significant improvement in the sound absorption coefficient value for 30% to 50% proportion of milkweed fibre in the blend. The minimum value of the sound absorption coefficient was achieved for stroke frequency 150/min for 30% milkweed fibre blend and the highest value at stroke frequency 350 /min was achieved for 70% of milkweed fibre in the blend%. Increase the stroke frequency along with an increase in the blend% significantly affect the sound absorption coefficient for the proportion of milkweed fibre in blend 40 to 70%. An increase in the stroke frequency from 325/min to 350/min gives the best results. An increase in the stroke frequency gives good sound absorption properties because of an increase in the pore in the nonwoven structure, which entraps the sound wave in the structure. Furthermore, an increase in the stroke frequency makes the fabric more compact, because of which the average pore size decrease with more pore per unit area. These small pores create obstacles to the path of the sound wave and also increase the friction resistance, therefore increasing the sound absorption properties of the fabric [38, 177].

5.2.1.3 Interactive effect of milkweed fibre blend% and needle depth on sound absorption coefficient

The contour plot in Figure 5.22 shows the effects of milkweed fibre blend% and needle depth on sound absorption coefficient for certain hold values of carded web mass, stroke frequency and sound frequency. As shown in Figure 5.22, the proportion of milkweed

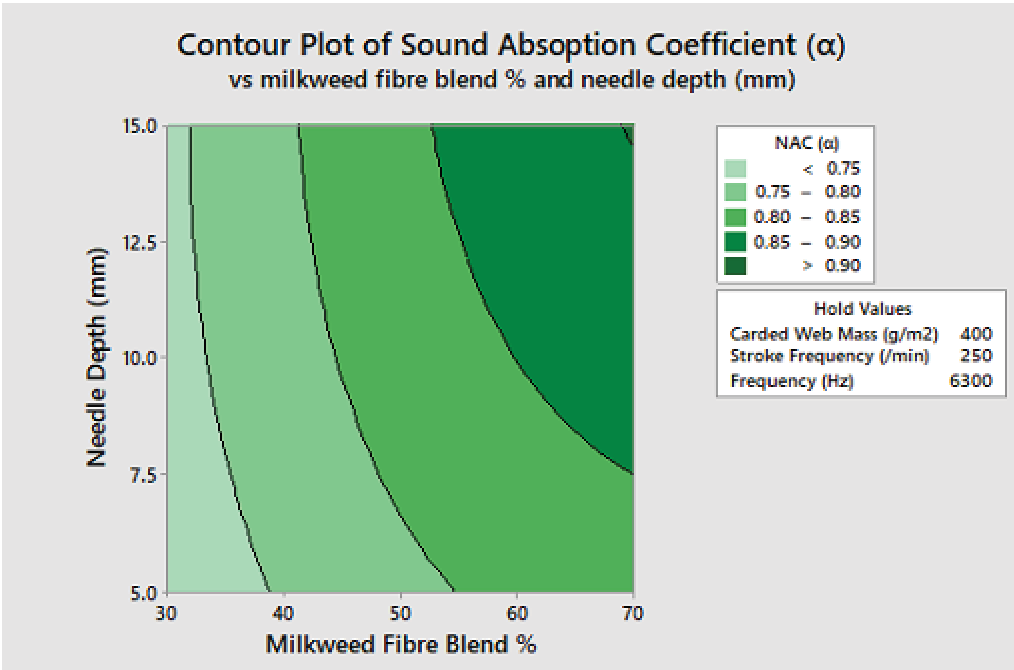

Figure 5.22: Effect of milkweed fibre blend% and needle depth on sound absorption coefficient

fibre in the blend% and needle depth have considerable influence on the sound absorption coefficient. It is clear from the graph that it is similar to the contour plot of milkweed fibre blend% and stroke frequency. The highest values of the sound absorption coefficient are in the upper right corner of the plot, which corresponds with high values of both milkweed fibre blend% and needle depth. The lowest values of the sound absorption coefficient are in the lower left corner of the plot, which corresponds with low values of milkweed fibre blend% and needle depth (mm). The lowest value of the sound absorption coefficient was achieved with 30% milkweed fibre proportion in the blend and 5 to 15 mm needle depth. The highest sound absorption value was achieved for milkweed fibre blend% 70 and 15 mm needle depth. The sound absorption value >0.9 was achieved with 60 to 70% of milkweed fibre proportion in blend and needle depth 7.5 mm to 15 mm. It is clear from the graph that as the proportion of milkweed fibre in the blend increased the sound absorption coefficient also increase. A nonwoven fabric made of milkweed fibre gives higher sound absorption due to its hollow structure, low density and fineness [44, 80, 176]. Figure 5.22 shows that as the needle depth increase, there is an increase in the sound absorption coefficient. the lowest value of the sound absorption coefficient was achieved with needle penetration depth 5 mm for 30% milkweed fibre proportion in the blend and the highest value at 15 mm needle depth for 70% milkweed fibre proportion in the blend was achieved. Increasing the needle depth along with an increase in the blend% significantly affects the sound absorption coefficient. There was no significant improvement observed in the sound absorption properties of the fabric, with increasing needle depth from 7.5 to 15 mm for same fibre blend%. An increase in the needle depth gives good sound absorption properties because of the intense fibre entanglement, which increases in numbers of small pore size that entrap the sound wave in the structure. More number of small pores increase the frictional resistance to a sound wave, because of which the more energy dissipated and increase the sound absorption properties of the nonwoven fabric [176, 177].

5.2.1.4 Interactive effect of carded web mass and stroke frequency on sound absorption coefficient

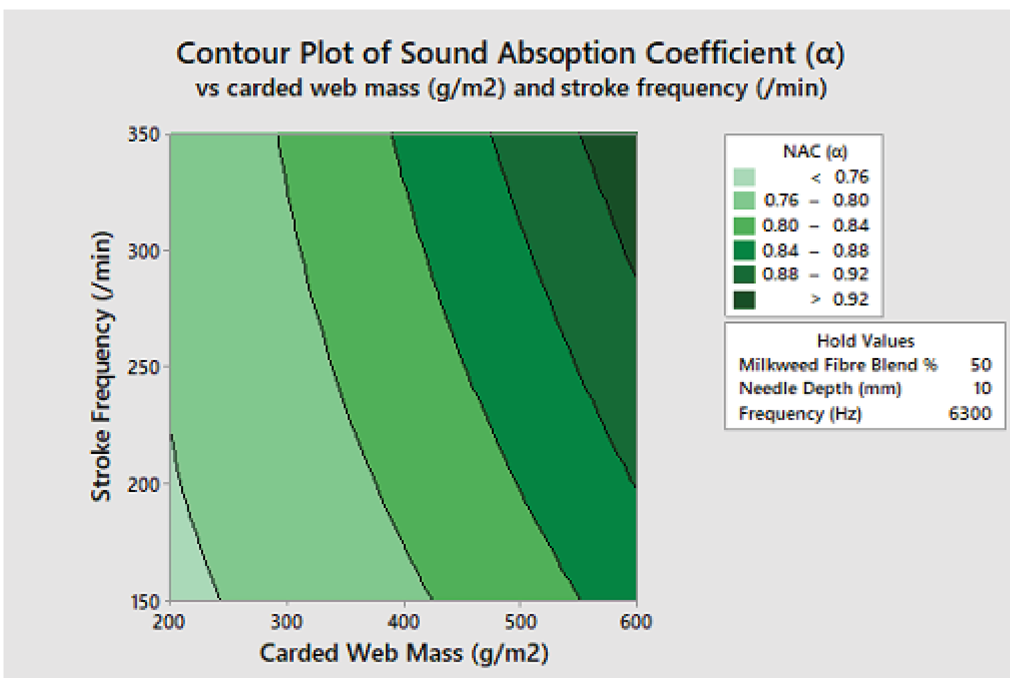

Figure 5.23: Effect of carded web mass and stroke frequency on sound absorption coefficient

Contour plot in Figure 5.23 shows the effect of carded web mass and stroke frequency on the sound absorption properties of milkweed fibre nonwoven fabric. The contour plot in Figure 5.23 shows the effects of carded web mass (g/m^2) and stroke frequency (/min) on sound absorption coefficient for certain hold values of milkweed fibre blend%, needle depth and sound wave frequency. Figure 5.23, show that the proportion of carded web mass and stroke frequency have a significant effect on the sound absorption property of milkweed fibre nonwoven fabric at 6300 Hz frequency as all values are above 0.5. The highest values of the sound absorption coefficient are in the upper right corner of the plot, which corresponds with high values of both carded web mass (g/m^2) and stroke frequency (/min). The lowest values of the sound absorption coefficient are in the lower left corner of the plot, which corresponds with low values of milkweed fibre blend% and carded web mass (g/m^2). The lowest value of the sound absorption coefficient was achieved with 200 g/m^2 carded web mass and 150/min stroke frequency. The highest sound absorption value was achieved with carded web mass 600 g/m^2 and stroke frequency 350/min. The sound absorption value >0.92 was achieved with carded web mass 560 g/m^2 to 600 g/m^2 and stroke frequency 290/min to 350/min. It is clear from the graph that as the carded web mass increased the sound absorption coefficient linearly increase. The highest value of the sound absorption coefficient was achieved for carded web mass 600 g/m^2. Increase in the carded web mass increase the number of fibre in the nonwoven fabric structure, so when the sound wave interacts with the nonwoven fabric it offers higher resistance to the incident sound wave due to increase in the air/fibre boundaries [37, 79, 177] and gives higher sound absorption coefficient values of nonwoven fabric. Figure 5.23 shows that for stroke frequency 150/ min to 350/min, the sound absorption coefficient value is more than 0.5 at 6300 Hz frequency, which indicates good sound absorption properties. As the stroke frequency increase there is an increase in the sound absorption coefficient value and the best results were obtained at 290/min to 350/min stroke frequency. Increase in the stroke frequency from 150/min to 200/min for fix carded web mass, there was no significant change in the sound absorption values observed. There was no change in the sound absorption coefficient value up to 300 g/m^2 with an increase in the stroke frequency from 150/min to 350/min. This is due to no change in the small pores and tortuosity which occur at higher punch density [177]. An increase in the stroke frequency gives good sound absorption properties because of an increase in the pore in the nonwoven structure, which entraps the sound wave in the structure. Furthermore, an increase in the stroke frequency makes the fabric more compact, because of which the average pore size decrease with more pore per unit area. These small pores create obstacles to the passage of the sound wave, because of which there is an increase in the friction resistance, therefore increasing the sound absorption properties of the fabric [38].

5.2.1.5 Interactive effect of carded web mass and needle depth on sound absorption coefficient

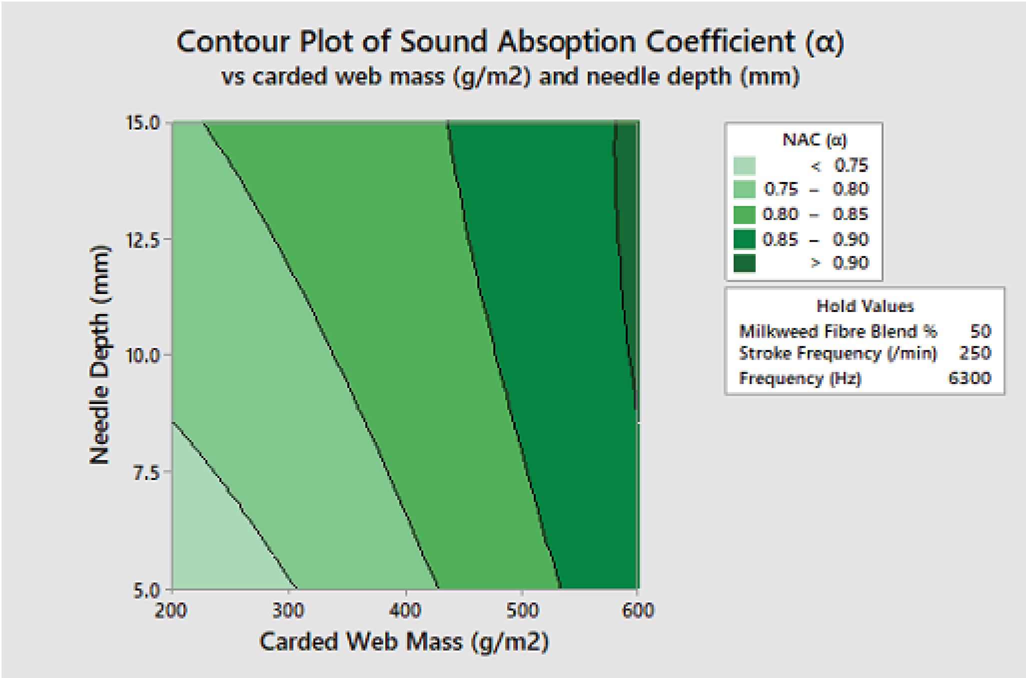

Figure 5.24: Effect of carded web mass and needle depth on sound absorption coefficient

Figure 5.24 shows the contour plot of the interaction effect of carded web mass and needle depth on the sound absorption coefficient of milkweed fibre nonwoven fabric for certain hold values of milkweed fibre blend%, stroke frequency and sound wave frequency. Figure 5.24, show that the proportion of carded web mass and needle depth have a significant effect on the sound absorption property of milkweed fibre nonwoven fabric at 6300 Hz frequency as all values are above 0.5. The highest values of the sound absorption coefficient are in the upper right corner of the plot, which corresponds with high values of both carded web mass (g/m^2) and needle depth (mm). The lowest values of the sound absorption coefficient are in the lower left corner of the plot, which corresponds with low values of carded web mass (g/m^2) and needle depth (mm). The lowest value of the sound absorption coefficient was achieved with 200 g/m^2 carded web mass and 5 mm needle penetration depth. The highest sound absorption value was achieved for carded web mass 600 g/m^2 and needle depth 15 mm. The sound absorption value >0.9 was achieved with carded web mass 590 g/m^2 to 600 g/m^2 and needle depth 8.5 mm to 15 mm. It is clear from the graph that as the carded web mass increased the sound absorption coefficient linearly increase. The highest value of the sound absorption coefficient was achieved for carded web mass 600 g/m^2. Increase in the carded web mass increase the number of fibre in the nonwoven fabric structure, so when the sound wave interacts with the nonwoven fabric it offers higher resistance to the incident sound wave due to increase in the air/fibre boundaries [37, 79, 177] and gives higher sound absorption coefficient values for nonwoven fabric. Figure 5.24 shows that as the needle depth increase, there is an increase in the sound absorption coefficient. The lowest value of the sound absorption coefficient was achieved with needle penetration depth 5 mm and the highest value at 15 mm was achieved. Increasing the needle depth along with an increase in the carded web mass significantly affects the sound absorption coefficient. There was no improvement in sound absorption properties of the fabric observed with an increase in needle depth from 5 mm to 7.5 mm for same fibre blend%. But as the needle depth increase from 5 mm to 10 mm with an increase in the carded web mass shows improvement in the sound absorption properties of the nonwoven fabric. An increase in the needle depth gives good sound absorption properties because of the intense fibre entanglement, which increases in numbers of small pore size that entrap the sound wave in the structure. More number of small pores increase the frictional resistance to a sound wave, because of which the more energy dissipated and increase the sound absorption properties of the nonwoven fabric achieved [176, 177].

5.2.1.6 Interactive effect of stroke frequency and needle depth on sound absorption coefficient

Figure 5.25 shows the contour plot of the interaction effect of stroke frequency and needle depth on the sound absorption coefficient of milkweed fibre nonwoven fabric for certain hold values of milkweed fibre blend%, carded web mass and sound frequency. As indicated in Figure 5.25, show that the proportion of stroke frequency and needle depth have a significant effect on the sound absorption property of milkweed fibre nonwoven fabric at 6300 Hz frequency as all values are above 0.5. The highest values of the sound absorption coefficient are in the upper right corner of the plot, which corresponds with high values of both stroke frequency (/min) and needle depth (mm). The lowest values of the sound

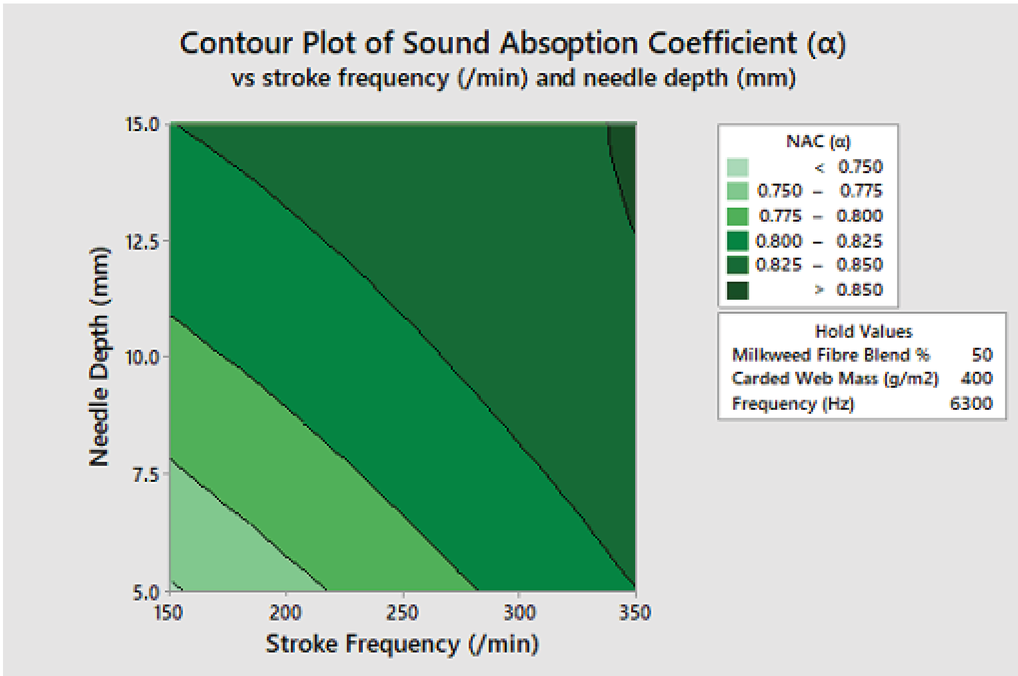

Figure 5.25: Effect of stroke frequency and needle depth on sound absorption coefficient

absorption coefficient are in the lower left corner of the plot, which corresponds with low values of stroke frequency (/min) and needle depth (mm). The lowest value of the sound absorption coefficient was achieved with stroke frequency 150/min and 5 mm needle penetration depth. The highest sound absorption value was achieved with stroke frequency 350/min and needle depth 15 mm. The sound absorption value >0.85 was achieved with stroke frequency 340 to 350/min and needle depth 12.5 mm to 15 mm. It is clear from the graph that as stroke increased the sound absorption coefficient increase. An increase in the stroke frequency gives good sound absorption properties because of an increase in the pore in the nonwoven structure, which entraps the sound wave in the structure. Furthermore, an increase in the stroke frequency makes the fabric more compact, because of which the average pore size decrease with more pore per unit area. These small pores create obstacles to the passage of the sound wave, because of which there is an increase in the friction resistance, therefore increasing the sound absorption properties of the fabric [38, 177]. As shown in the contour plot in figure 5.25, shows that Increase in the needle depth from 5.0 to 7.5 mm, 7.5 to 10 mm, 10 to 12.5 mm and 12.5 to 15 mm for fix stroke frequency, there was no change in the sound absorption values. This is due to no change in the small pores and tortuosity which occur at higher needle depth penetration [177]. But an increase in the needle depth from 5.0 to 10 mm, 7.5 to 12.5 mm and 10 to 15 mm for fix stroke frequency would increase the sound absorption coefficient. An increase in the needle depth gives good sound absorption properties because of the intense fibre entanglement, which increases in numbers of small pore size that entrap the sound wave in the structure. More number of small pores increase the frictional resistance to a sound wave, because of which the more energy dissipated and increase the sound absorption properties of the nonwoven fabric [176].

5.2.1.7 Analysis of Variance for the sound absorption coefficient of Milkweed fibre nonwoven fabric

The results of the sound absorption coefficient for a different proportion of milkweed fibre in the blend% and needle depth are shown in Appendix I (Table 4). Sound absorption coefficient results are analyzed using the response surface method with the help of Minitab 18 software. Four continuous factors like milkweed fibre proportion in the blend%, carded web mass (g/m^2), stroke frequency (/min) of needle punch machine, needle depth (mm), and one categorical factor sound frequency (Hz) are selected as variables and corresponding coded variable are given in Table 5.16.

Table 5.16: Coded variable of milkweed fibre variables

Variables	Coded variables
Milkweed fibre blend %	Y_1
Carded web mass (g/m^2)	Y_2
Stroke frequency (/min)	Y_3
Needle depth (mm)	Y_4
Frequency (Hz)	Y_5

Analysis of variance (ANOVA) values for the regression model obtained from CCD employed in the optimization of process parameters. On the basis of obtained experimental values, statistical testing carried out using ANOVA test at 95% confidence level. ANOVA regression model for the sound absorption coefficient of milkweed fibre nonwoven fabric depicted in the following Table 5.17.

Table 5.17: ANOVA regression model for the sound absorption coefficient of milkweed fibre nonwoven fabric

Source	**Degree of freedom (DF)**	**Sum of squares (SS)**	**Mean of squares (MS)**	***F* Value**	***P* Value**
Model	54	19.0306	0.352419	798.94	<0.001
Linear	12	0.0684	0.005698	12.92	<0.001
Y_1	1	0.0229	0.022887	51.88	<0.001
Y_2	1	0.0071	0.007086	16.06	<0.001
Y_3	1	0.0006	0.000596	1.35	0.246
Y_4	1	0.0029	0.002891	6.55	0.011
Y_5	8	0.0354	0.004431	10.04	<0.001
Square	4	0.0097	0.002417	5.48	<0.001
${Y_1}^2$	1	0.0056	0.005607	12.71	<0.001
${Y_2}^2$	1	0.0025	0.002489	5.64	0.018
${Y_3}^2$	1	0	0.000034	0.08	0.782
${Y_4}^2$	1	0.0008	0.000789	1.79	0.182
2-Way Interaction	38	0.0725	0.001907	4.32	<0.001
$Y_1 * Y_2$	1	0.0238	0.023767	53.88	<0.001
$Y_1 * Y_3$	1	0.0029	0.002934	6.65	0.011
$Y_1 * Y_4$	1	0.0014	0.001406	3.19	0.076
$Y_1 * Y_5$	8	0.0205	0.002567	5.82	<0.001
$Y_2 * Y_3$	1	0.0031	0.003117	7.07	0.008
$Y_2 * Y_4$	1	0.002	0.001951	4.42	0.037
$Y_2 * Y_5$	8	0.0139	0.001736	3.94	<0.001
$Y_3 * Y_4$	1	0.0014	0.001406	3.19	0.076
$Y_3 * Y_5$	8	0.0021	0.000258	0.59	0.789
$Y_4 * Y_5$	8	0.0014	0.000176	0.4	0.921
Error	224	0.0988	0.000441		
Lack of fit	170	0.0865	0.000509	2.23	<0.001
Pure Error	54	0.0123	0.000228		

Source	**Degree of freedom (DF)**	**Sum of squares (SS)**	**Mean of squares (MS)**	***F* Value**	***P* Value**
Total	278	19.1294			
Model Summary					
Square	:	0.0206385			
R^2	:	99.46%			
R^2 (adj)	:	99.38%			
R^2 (pred)	:	99.29%			

Here, Minitab 18 software used for statistical data analysis. The effect of independent parameters milkweed fibre proportion in blend%, carded web mass (g/m^2), stroke frequency (/min), needle depth (mm) and sound frequency (Hz) on the dependent parameter sound absorption coefficient examined for 31 milkweed fibre nonwoven fabric with analysis of variance at a significance level of value p less than 0.05. The model summary and ANOVA results of obtained results depicted in Table 5.17

Analysis of variance (ANOVA) analysis of milkweed fibre nonwoven fabric carried out. It indicates that the milkweed fibre proportion in blend%, carded web mass (g/m^2), sound wave frequency (Hz), needle depth (mm) are significantly influence the sound absorption coefficient of the fabric. According to the F values, milkweed fibre proportion in blend%, carded web mass (g/m^2), sound frequency (Hz), needle depth (mm) are more significantly affect the sound absorption coefficient than stroke frequency.

ANOVA analysis of Square and 2-way interaction shows that interaction between the milkweed fibre proportion in the blend% and milkweed fibre proportion in the blend%, carded web mass (g/m^2) and carded web mass (g/m^2), milkweed fibre proportion in the blend% and carded web mass (g/m2), milkweed fibre proportion in the blend% and frequency (Hz), carded web mass (g/m^2) and stroke frequency (/min), milkweed fibre proportion in the blend% and stroke frequency (/min), carded web mass (g/m^2) and frequency (Hz), carded web mass(g/m^2) and neddle depth (mm) significantly influence the sound absorption coefficient of the milkweed fibre nonwoven fabric. According to the F value, the interaction between the milkweed fibre proportion in blend% and carded web mass (g/m^2) highly influences the sound absorption coefficient. Statistical analysis at p-value 0.05 indicates that interaction between milkweed fibre proportion in blend%

and neddle depth (mm), stroke frequency (/min) and frequency (Hz), neddle depth (mm) and frequency (Hz), and stroke frequency (/min) and neddle depth (mm) have shown insignificant influence on the sound absorption coefficient of milkweed fibre nonwoven fabric.

The model summary given in Table 5.17. It is observed that the R-Squared value is 99.46%, which indicate that sound absorption coefficient of milkweed fibre nonwoven fabric is affected by the fibre proportion in blend%, carded web mass (g/m^2), stroke frequency (/min), needle depth (mm) and sound frequency (Hz) with confidence level 99.46%. The model predicts the sound absorption coefficient successfully at a level of 99.29%. The p-value $0.001 < 0.05$ indicates the model is statistically highly significant.

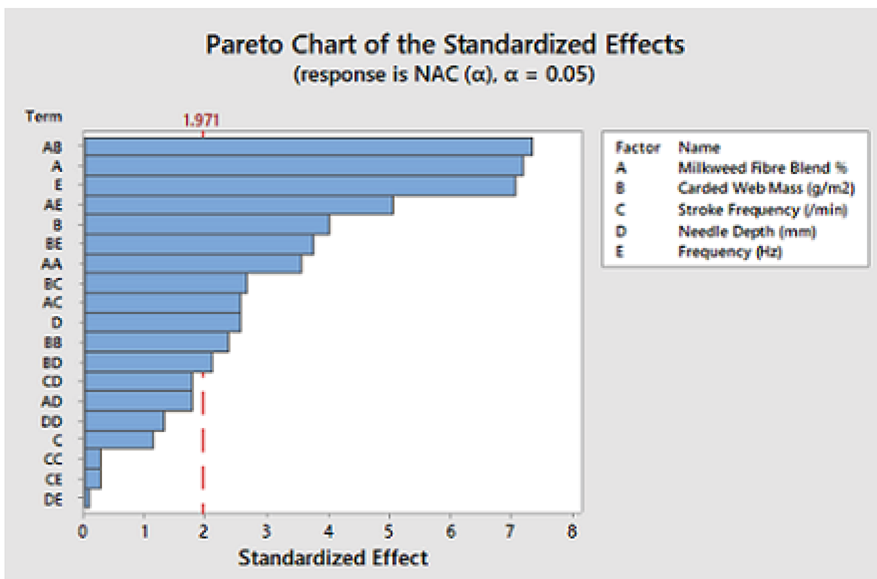

Figure 5.26: Pareto chart for process parameters of milkweed fibre nonwoven fabric

Figure 5.26 and 5.27 shows the Pareto chart and Normal plot of the standardized effects for sound absorption coefficient which indicate that the fibre proportion in the blend, frequency, and the interaction between milkweed fibre proportion in blend% and carded web mass have a strongest significant influence on the sound absorption coefficient and followed by carded web mass, the interaction between milkweed fibre proportion in belnd% and frequency, carded web mass and frequency, milkweed fibre proportion in blend% and milkweed fibre proportion in blend%, carded web mass and stroke frequency, milkweed fibre proportion in blend% and stroke frequency, needle depth, carded web mass and carded web mass, carded web mass and needle depth have a significant influence on

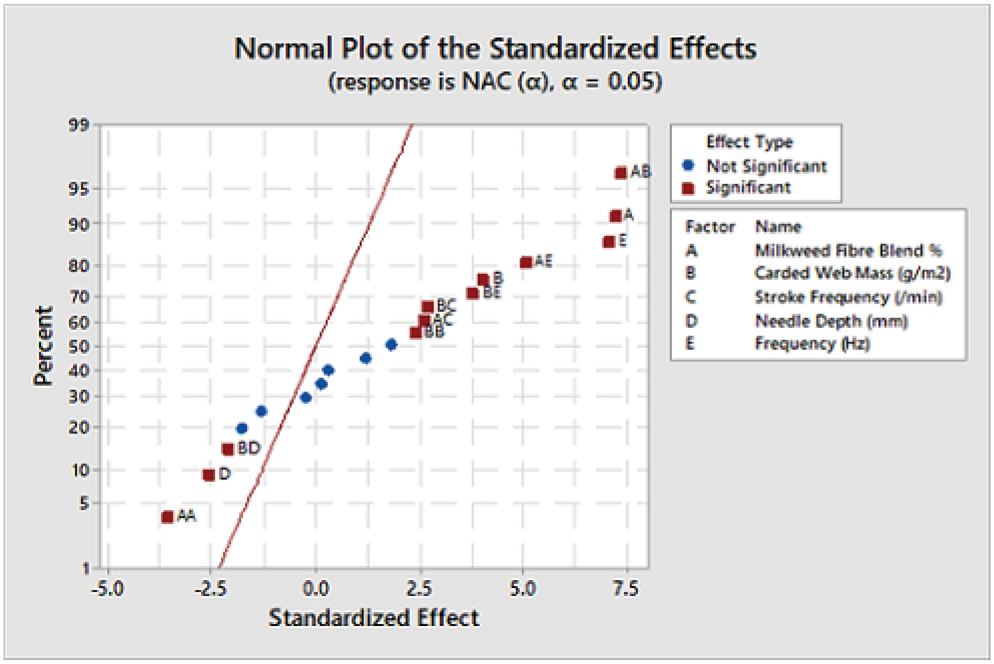

Figure 5.27: Normal plot for process parameters of milkweed fibre nonwoven fabric

the sound absorption coefficient of the nonwoven fabric.

5.2.1.8 Regression Analysis: Milkweed fibre nonwoven fabric

The regression analysis of NAC (α) versus milkweed fibre blend%, carded web mass, stroke frequency and needle depth without considering interactive effect of selected parameters at a various frequency discussed below. The regression equation of NAC (α) versus milkweed fibre blend%, carded web mass, stroke frequency, needle depth and its interactive effect at a various frequency (Hz) given in Appendix III (Table 3).

By multiple regression analysis, the coefficient of different parameters and their probability value p-value at a 95% confidence interval were calculated with the help of Minitab 18 software, and results are shown in Table 5.18.

Table 5.18: Estimated regression coefficient and corresponding p-value for Milkweed fibre nonwoven fabric

Term	Coef	SE Coef	*P*-Value
Constant	-0.3089	0.0167	<0.001

Term	Coef	SE Coef	P-Value
Y_1	0.003227	0.000177	<0.001
Y_2	0.000372	0.000018	<0.001
Y_3	0.000179	0.000035	<0.001
Y_4	0.00387	0.00071	<0.001
Y_5			
250	0.000000	0.000000	*
500	0.02516	0.00662	<0.001
1000	0.0871	0.00662	<0.001
2000	0.17419	0.00662	<0.001
2500	0.34	0.00662	<0.001
3150	0.44677	0.00662	<0.001
4000	0.52645	0.00662	<0.001
5000	0.63516	0.00662	<0.001
6300	0.73323	0.00662	<0.001

The following equation shows the regression analysis of NAC (α) versus milkweed fibre proportion in the blend%, carded web mass, stroke frequency and needle depth without considering its interactive effect at a various frequency.

$$\begin{aligned} NAC(\alpha) = & -0.3089 + 0.003227Y_1 + 0.000372Y_2 + 0.000179Y_3 + 0.003870Y_4 \\ & + 0.0Y_5(250Hz) + 0.02516Y_5(500Hz) + 0.08710Y_5(1000Hz) \\ & + 0.17419Y_5(2000Hz) + 0.34000Y_5(2500Hz) + 0.44677Y_5(3150Hz) \\ & + 0.52645Y_5(4000Hz) + 0.63516Y_5(5000Hz) + 0.73323Y_5(6300Hz) \end{aligned} \tag{5.5}$$

From the obtained coefficient value of the parameters, it can be said that sound wave frequency and fibre proportion in the blend played a dominant role among all the selected parameters, which also observed from the Pareto chart. The needle depth and carded web mass show the second and third-largest impact on the sound absorption coefficient of the milkweed fibre nonwoven fabric respectively.

The regression equation of NAC (α) versus milkweed fibre blend%, carded web mass, stroke frequency, needle depth and its interactive effect at a various frequencies are given in Appendix III. Following regression equation indicate the sound absorption coefficient

(α) versus milkweed fibre blend%, carded web mass, stroke frequency, needle depth and its interactive effect at frequency 6300 Hz.

$$\begin{aligned} NAC(\alpha) = 0.690 - 0.00052\ Y_1 - 0.000622Y_2 - \ 0.000243Y_3 + \ 0.01666Y_4 \\ - \ 0.000047Y_1 * Y_1 + \ 0.000000Y_2 * Y_2 - \ 0.000000Y_3 * Y_3 - \ 0.000280Y_4 * Y_4 \\ + \ 0.000013Y_1 * Y_2 + \ 0.000009Y_1 * Y_3 + \ 0.000125Y_1 * Y_4 + \ 0.000001Y_2 * Y_3 \\ - \ 0.000015Y_2 * Y_4 - \ 0.000025Y_3 * Y_4 \end{aligned} \quad (5.6)$$

It was observed that the best sound absorption coefficient value achieved at sound wave frequency 6300 Hz. From the above equation and Appendix III (Table 3) for the obtained coefficient value of the parameters, it can be said that The interaction between fibre proportion in the blend and carded web mass played a dominant role among all the selected parameters, followed by carded web mass, milkweed fibre proportion in the blend and sound frequency which also observed from the Pareto chart. The needle depth and stroke frequency also show their influence on the sound absorption coefficient of the milkweed fibre nonwoven fabric, but the effect of stroke frequency is not significant. The interaction between needle depth and sound frequency played the least impactful role in determining the sound absorption coefficient. It is observed that all the selected parameters show a significant influence on the sound absorption coefficient of milkweed fibre nonwoven fabric except stroke frequency. Other regression equations with interactive effect at various frequencies are given in Appendix III (Table 3).

In following Table 5.19 the regression coefficient values of different parameters of kapok and milkweed fibre fabric are compare with each other to understand the effect of fibre type on the sound absorption coefficient, because all the selected variables (expect fibre types) are same for both the fabric.

Table 5.19: Comparison of kapok and milkweed regression coefficient

Kapok fibre		Milkweed fibre		Difference in coefficient value
Term	Coef	Term	Coef	
X_1	0.0058	Y_1	0.0032	0.0026
X_2	0.0003	Y_2	0.0004	0.0000
X_3	0.0005	Y_3	0.0002	0.0003
X_4	0.0049	Y_4	0.0039	0.0011

Kapok fibre		Milkweed fibre		Difference in coefficient value
Term	Coef	Term	Coef	
X_5		Y_5		
250	0.0000	250	0.0000	0.0000
500	0.0558	500	0.0252	0.0306
1000	0.1348	1000	0.0871	0.0477
2000	0.3106	2000	0.1742	0.1364
2500	0.3884	2500	0.3400	0.0484
3150	0.5203	3150	0.4468	0.0735
4000	0.5948	4000	0.5265	0.0684
5000	0.6326	5000	0.6352	-0.0026
6300	0.6790	6300	0.7332	-0.0542

From the obtained results it can be said that there is a difference in the coefficient value of different frequencies because the sound absorption value at different frequencies also gets affected by the types of material and its structure. Here, among the selected continuous parameters difference in the coefficient values observed for the proportion of fibre in the blend and porosity followed by air permeability. There is a difference in coefficient value for the proportion of fibre in the blend, due to the difference in the fibre types used in the blend. Kapok fibre has a lower density and higher fineness compare to milkweed fibre, which increases the number of fibre in fabric. The surface area of fibre in the fabric increase, due to the more number of fibre in the fabric. Therefore, kapok fibre fabric gives higher sound absorption properties compared to milkweed fibre.

Statistic analysis for optimization of sound absorption coefficient indicates that the highest value of the sound absorption can be achieved with blend% 70, carded web mass g/m^2 600, stroke frequency 205, and needle depth 15 mm at 6300 Hz frequency. Table 5.20, and figure 5.28 indicate the Response optimization for sound absorption coefficient value which can be used to get the best possible value of sound absorption coefficient.

Table 5.20: Multiple response prediction: NAC(α)

Variable	**Setting**
Milkweed Fibre Blend %	70

Variable	**Setting**
Carded Web Mass (g/m2)	600
Stroke Frequency (/min)	205.357
Needle Depth (mm)	15
Frequency (Hz)	6300
Response	**NAC** (α)
Fit	0.9997
SE Fit	0.0222

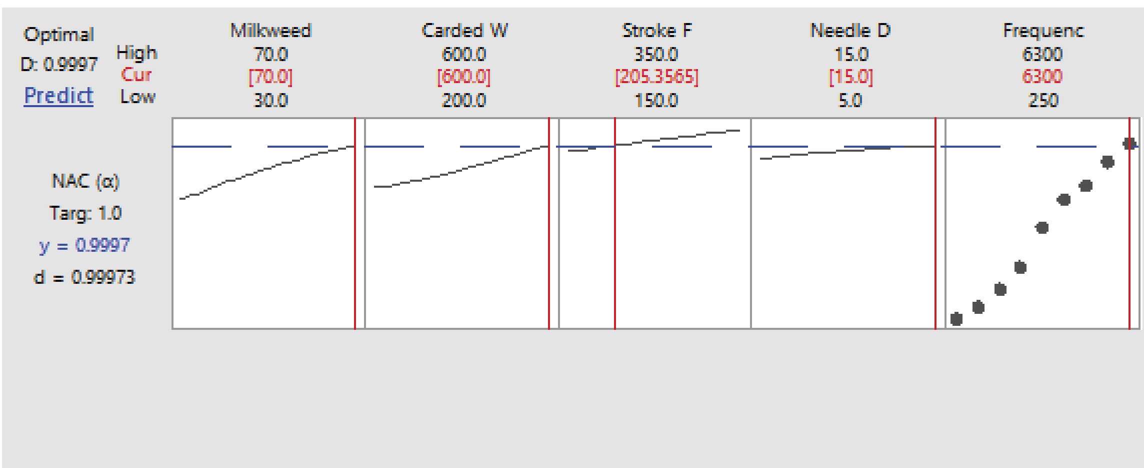

Figure 5.28: Optimization plot of Milkweed fibre nonwoven fabric

5.2.2 Effect of proportion of milkweed fibre in the blend on the sound absorption coefficient

Table 5.21: Average sound absorption coefficient value of milkweed fabric for different proportion of fibre in the blend at different frequency

Sr. No	**Blend % (Milkweed/ Modal)**	**Sound absorption coefficient value** (α) **at different frequency**								
		250 Hz	**500 Hz**	**1000 Hz**	**2000 Hz**	**2500 Hz**	**3150 Hz**	**4000 Hz**	**5000 Hz**	**6300 Hz**
1	30/70	0.03	0.05	0.11	0.19	0.31	0.45	0.53	0.60	0.71
2	40/60	0.07	0.08	0.16	0.23	0.39	0.48	0.57	0.69	0.78

Sr. No	Blend % (Milkweed/ Modal)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	500 Hz	1000 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz
3	50/50	0.08	0.11	0.16	0.26	0.43	0.51	0.62	0.74	0.83
4	60/40	0.11	0.14	0.20	0.30	0.45	0.62	0.64	0.73	0.84
5	70/30	0.11	0.13	0.23	0.30	0.48	0.59	0.68	0.76	0.89

The effect of the proportion of Estabragh (Milkweed) fibre on the sound absorption coefficient studied and averaged results depicted in Table 5.21. Sound absorption coefficient values indicate that the sound absorption coefficient increase with increase fibre proportion 30% to 70% in the blend% at frequency bands 250 Hz to 6300 Hz. Nonwoven fabric sample having 30% fibre proportion in the blend gives lowest sound absorption value 0.03 at frequency 250 Hz and highest sound absorption coefficient value 0.89 observed at frequency 6300 Hz with 70% milkweed fibre proportion in the blend. It is observed that the sound absorption values are below 0.5 up to a frequency of 2500 Hz for a different proportion of fibre in the blend, which indicates all samples show poor sound absorption property for frequency 250 Hz to 2500 Hz. In the frequency range 3150 Hz to 6300 Hz, most of the sound absorption values are above 0.5, which indicates the fabric having good sound absorbency and shows that the value of the sound absorption coefficient increase with the increase in the fibre proportion in the blend. Sample with 30% milkweed fibre in the blend gives sound absorption value are in the range of 0.03 to 0.71 for frequency 250 Hz to 6300 Hz. Sound absorption coefficient value are in the range of 0.07 to 0.78, 0.08 to 0.83, 0.11 to 0.84, and 0.11 to 0.89 for 40%, 50%, 60%, and 70% proportion of milkweed fibre in the blend% respectively from 250 Hz to 6300 Hz frequency. Sound absorption coefficient value of nonwoven fabric increase with the increase in the frequency value from 250 Hz to 6300 Hz. It can be said that the sound absorption coefficient of the nonwoven fabric increase with the increase in fibre proportion from 30% to 70% and gives excellent sound absorption properties at frequency 3150 Hz to 6300 Hz with the best performance at frequency 6300 Hz. Increased vibration of sound waves at higher frequencies resulted in frictional losses and absorption of sound energy within the structures. Thus, the sound absorption performance of milkweed nonwoven fabric improved at a higher frequency.

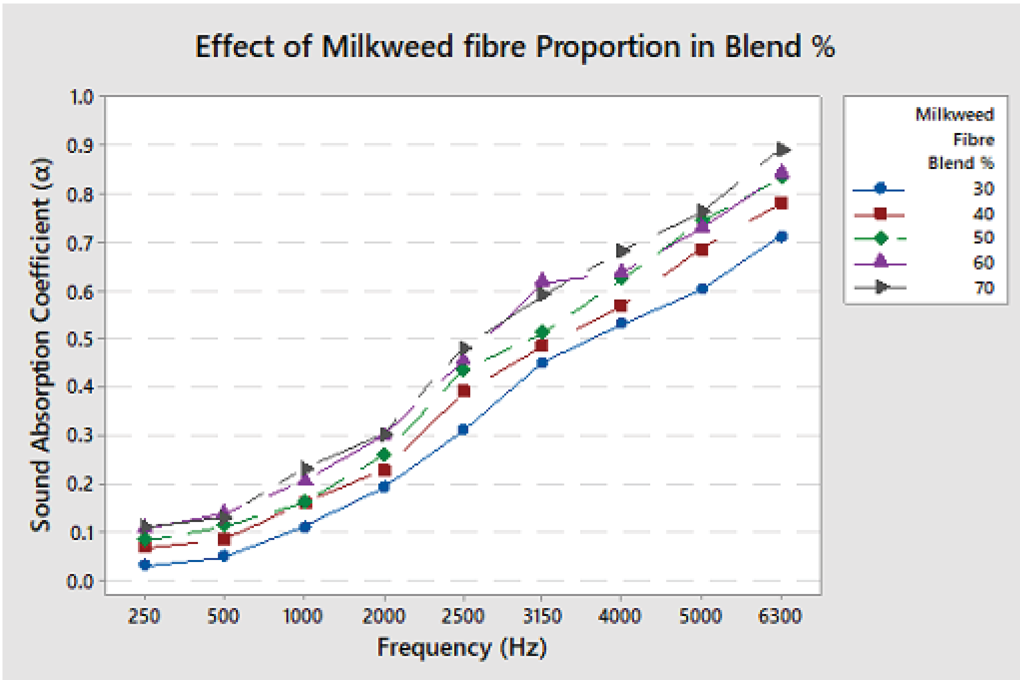

Figure 5.29: Effect of milkweed fibre proportion in blend on sound absorption coefficient

The natural hollow structure of milkweed (Estabragh) fibres leads to an increase in the surface area of the fibre. Larger fibre surface area influences the boundaries faced by the sound wave, which in turn leads to an increase in the sound absorption ability of the nonwoven fabric. Narang [176] stated in his research work, increase friction between fibre and air and its effect on sound absorption performance. Hollow fibre due to entrapment of air in their hollow lumen is expected to increase the sound absorption properties of the material by a twofold. Therefore, an increment in the milkweed fibre proportion of the blends leads to more frictional losses and a higher sound absorption coefficient. Figure 5.29 indicates the sound absorption coefficient graph for different fibre proportion in the blend at a different frequency. From the graph, it is clear that a higher proportion of milkweed fiber leads to increase sound absorbency of nonwoven fabric at high frequencies.

Previous research work [44], has also stated the importance of fibre diameter and fineness on the sound absorption properties of the material. Milkweed fibre due to low density and fineness, a nonwoven fabric made out of milkweed fibre has a higher number of fibres. It leads to an increase in the surface area of fibre in fabric, which results in higher sound absorption. It explains the excellent sound absorption properties of the sample composed of a higher proportion of milkweed fibre.

5.2.3 Effect of carded web mass on the sound absorption coefficient

Table 5.22: Average sound absorption coefficient value of milkweed fabric for different carded web mass at different frequency

Sr. No	Carded Web Mass (g/m^2)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	500 Hz	1000 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz
1	200	0.02	0.07	0.12	0.18	0.34	0.44	0.51	0.64	0.74
2	300	0.07	0.08	0.15	0.22	0.38	0.51	0.56	0.66	0.78
3	400	0.08	0.11	0.16	0.25	0.43	0.51	0.62	0.73	0.83
4	500	0.10	0.14	0.21	0.30	0.46	0.59	0.64	0.76	0.84
5	600	0.17	0.20	0.26	0.36	0.56	0.63	0.74	0.82	0.91

The effect of the carded web mass on the sound absorption coefficient studied and averaged results of milkweed fibre nonwoven fabrics depicted in Table 5.22. Obtained results indicate that the sound absorption coefficient of nonwoven fabric increase linearly with increased carded web mass. Sound absorption coefficient values are increased from 0.02 to 0.17 by about 750% at frequency 250 Hz, 0.07 to 0.20 by about 186% at frequency 500 Hz, 0.12 to 026 by about 117% at frequency 1000 Hz, 0.18 to 0.36 by about 100% at frequency 2000 Hz and 0.34 to 0.56 by about 65% at frequency 2500 Hz with increased carded web mass from 200 g/m^2 to 600 g/m^2. In the frequency range, 250 Hz to 2500 Hz sound absorption coefficient values remain below 0.5 except for carded web mass 600 g/m^2 value of sound absorption coefficient 0.56 at frequency 2500 Hz.

Though the sound absorption coefficient value increases significantly in terms of percentage, value below 0.5 shows poor performance of the nonwoven fabric produced by using a milkweed fibre in frequency ranges 250 Hz to 2500 Hz. Sound absorption coefficient value of nonwoven fabric increased 0.44 to 0.63 by about 43% at frequency 3150 Hz, 0.51 to 0.74 by about 45% at frequency 4000 Hz, 0.64 to 0.82 by about 28% at frequency 5000 Hz, and 0.74 to 0.91 by about 23% at frequency 6300 Hz with increase carded web mass from 200 g/m^2 to 600 g/m^2. Here it is observed that the value of the

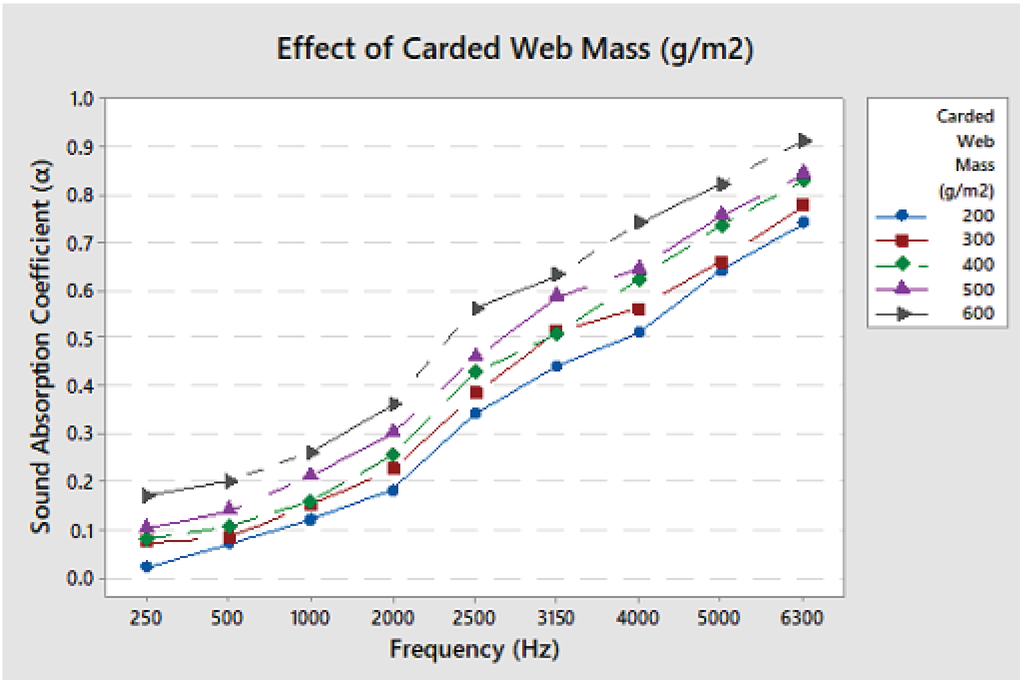

Figure 5.30: Effect of milkweed fibre carded web mass on sound absorption coefficient

sound absorption coefficient increase in terms of percentage in the frequency range from 3150 Hz to 6300 Hz is not so high as compared to frequency range 250 Hz to 2500 Hz. However, except one value, all value is above 0.5, means in this frequency range milkweed fibre nonwoven fabric shows good sound absorption property and sound absorption value increase with increased carded web mass at a fixed frequency. All sample shows a peak value of sound absorption coefficient 0.74 for 200 g/m^2, 0.78 for 300 g/m^2, 0.83 for 400 g/m^2, 0.84 for 500 g/m^2, and 0.91 for 600 g/m^2 at frequency 6300 Hz. It indicates that all sample shows excellent sound absorption at 6300 Hz frequency and sound absorption value increased with increased carded web mass 200 g/m^2 to 600 g/m^2. Milkweed fibre nonwoven fabric samples with 600 g/m^2 carded web mass give the highest value 0.91 of sound absorption coefficient at frequency 6300 Hz.

It was found that the sound absorption coefficient of nonwoven needle punches fabric increase linearly with an increase in the mass of the carded web. Figure 5.30 indicate the effect of the carded web mass on sound absorption of milkweed fiber nonwoven fabric. It also supported by the earlier research work done by Tascan and Vaughn [37]. The increase in the carded web mass leads to an increase in the higher number of fibre within the material, which will increase the air/fibre boundaries within nonwoven needle punch fabric. The air/fibre boundaries will offer higher resistance to the incident sound wave, when sound waves interact with nonwoven material and leads to an increase the sound absorbency.

5.2.4 Effect of stroke frequency on the sound absorption coefficient

Table 5.23: Average sound absorption coefficient value of milkweed fabric for different stroke frequency at different sound frequency

Sr. No	Stoke Frequency (/min)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	500 Hz	1000 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz
1	150	0.07	0.10	0.15	0.23	0.41	0.48	0.56	0.70	0.80
2	200	0.08	0.10	0.18	0.26	0.41	0.54	0.60	0.70	0.80
3	250	0.08	0.11	0.16	0.26	0.43	0.51	0.62	0.74	0.83
4	300	0.10	0.12	0.18	0.27	0.43	0.56	0.61	0.71	0.82
5	350	0.10	0.10	0.18	0.28	0.47	0.56	0.66	0.75	0.86

The effect stoke frequency of needle punch loom on the sound absorption coefficient studied and averaged of obtained results enumerated in Table 5.23. It indicates that the sound absorption coefficient value increased with an increase in a stroke frequency from 150 /min to 350 /min. Milkweed fibre nonwoven fabric sound absorption coefficient increased from 0.07 to 0.10 at frequency 250 Hz, 0.10 to 0.10 at frequency 500 Hz, 0.15 to 0.18 at frequency 1000 Hz, 0.23 to 0.28 at frequency 2000 Hz, and 0.41 to 0.47 at frequency 2500 Hz. The sound absorption coefficient increased with increased stroke frequency of needle punch loom from 150 /min to 350 /min, but its value is below 0.5 shows poor sound absorbency of the fabric in this frequency range. In the frequency range from 3150 to 6300 Hz, the value of the sound absorption coefficient is above 0.5, which indicates the excellent sound absorption properties of milkweed fabric and also shows that its values increased with increased needle punch loom stroke frequency. Sound absorption coefficient value of milkweed fabric increased from 0.07 to 0.80 for stroke frequency 150 /min, 0.08

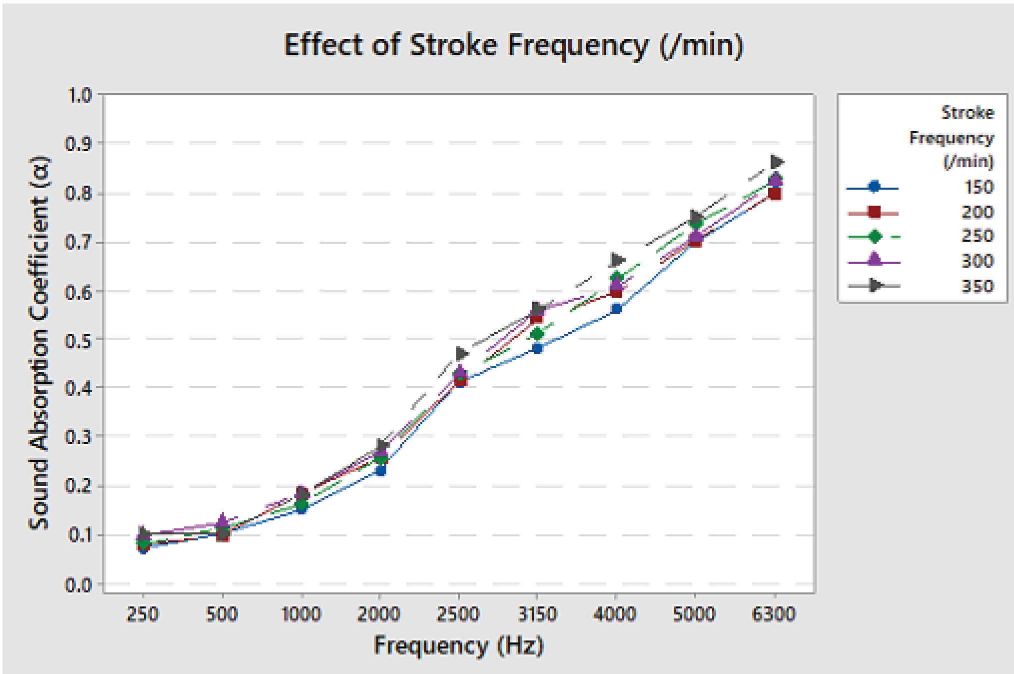

Figure 5.31: Effect of stroke frequency on sound absorption coefficient

to 0.80 for stock frequency 200 /min, 0.08 to 0.83 for stroke frequency 250 /min, 0.10 to 0.82 for stroke frequency 300 /min, and 0.10 to 0.86 for stroke frequency 350 /min as the frequency value increased from 250 Hz to 6300 Hz. It indicates that the sound absorption coefficient value of nonwoven fabric increase as the frequency value increase from 250 Hz to 6300 Hz. The stroke frequency of needle punch machine 150 /min gives value 0.80, 200 /min gives 0.80, 250 /min gives 0.83, 300 /min gives 0.82, and 350 /min gives value 0.86 of sound absorption coefficient at 6300 Hz frequency.

Figure 5.31 shows the effect of stroke frequency of the sound absorption coefficient on milkweed fibre nonwoven fabric. It shows almost linear increasing trends of the sound absorption coefficient of nonwoven needle punched samples with an increase in stroke frequency. Arrangement of fibre in the structure plays a vital role to increase the fibre to fibre contact within the nonwoven structure. Interaction of incident sound wave depends on the number of fibre to the fibre contact point within the nonwoven structure. An increase in stroke frequency can lead to creating smaller pores in the nonwoven fabric. Increase the stroke frequency in the range of 150-350/min, leads to an increase in several pores which entrap the sound waves in the structure. It will help to increase the sound absorption properties of the material. From the graph, it is clear that the sound absorption coefficient of milkweed fibre nonwoven fabrics increased with an increase in frequency value for the fixed stroke frequency. It is observed that for milkweed fibre, increased in the sound absorption coefficient at frequency range 250 Hz to 2500 Hz was less as compared to kapok fibre nonwoven fabrics.

5.2.5 Effect of needle depth on the sound absorption coefficient

Table 5.24: Average sound absorption coefficient value of milkweed fabric for different needle depth at different sound frequency

Sr. No	Needle Depth (mm)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	500 Hz	1000 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz
1	5.00	0.06	0.09	0.11	0.23	0.40	0.53	0.59	0.71	0.81
2	7.50	0.08	0.10	0.17	0.25	0.41	0.54	0.59	0.69	0.79
3	10.00	0.08	0.11	0.16	0.26	0.43	0.51	0.62	0.73	0.83
4	12.50	0.09	0.12	0.19	0.27	0.43	0.56	0.61	0.72	0.83
5	15.00	0.11	0.13	0.19	0.24	0.43	0.51	0.63	0.75	0.84

The effect of the needle depth of needle punch machine on the sound absorption coefficient studied and the averaged results enumerated in Table 5.24. It is observed that increased needle depth from 5 mm to 15 mm leads to an increase in the sound absorption properties of the nonwoven fabric. Figure 5.32 shows the sound absorption coefficients values obtained of milkweed fibre nonwoven fabric for different needle depth. The increase of needle depth from 5 mm to 10 mm, 7.5 mm to 12.5 mm and 10 mm to 15 mm leads to an increase in the sound absorption properties of the material except for 15 mm needle depth at 2000 Hz. It was found that the change in needle depth from 5 mm to 7.5 mm, 7.5 mm to 10 mm, 10 mm to 12.5 mm, and 12.5 mm to 15 mm shows an increasing trend in the sound absorption coefficient. However, it does not affect the sound absorbency property of the material significantly. It is also observed that milkweed fibre nonwoven fabric sound absorption coefficient values are below 0.5 for frequency 250 Hz to 2500 Hz, indicate the poor sound absorption properties of the nonwoven fabric. Sound absorption

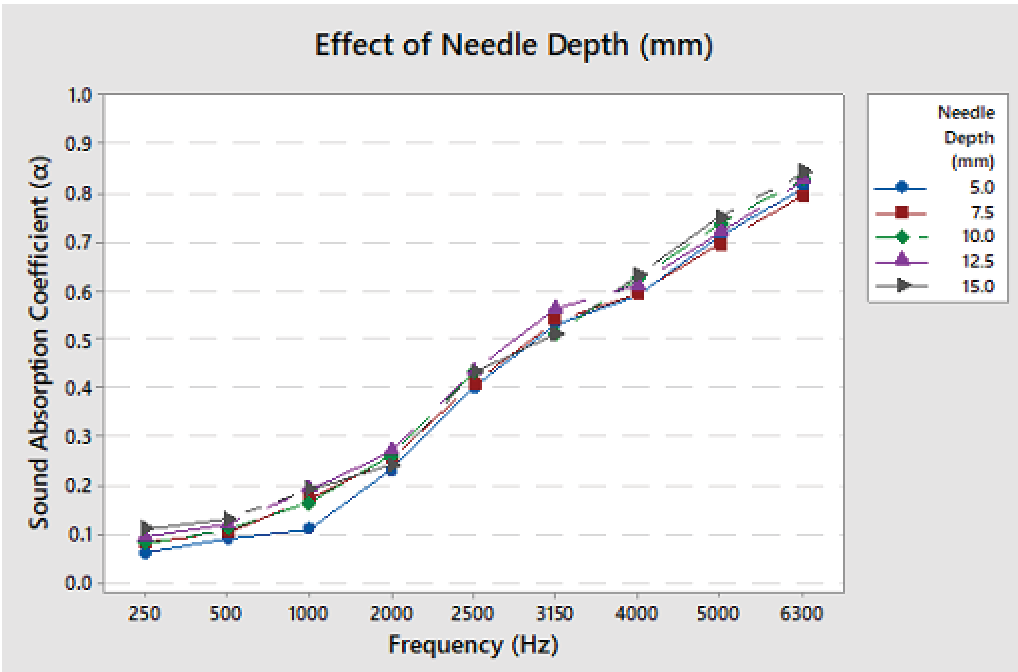

Figure 5.32: Effect of needle depth on sound absorption coefficient

coefficient value shows that for the frequency range from 3150 Hz to 6300 Hz, sound absorption coefficients values are above 0.5 with a peak value at 6300 Hz frequency, which indicates the good sound absorption properties of the nonwoven fabric. An increase in the needle depth results in intense fibre entanglement, which results in the formation of numbers of small pores that entrap the sound wave in the structure. It will increase the frictional resistance to sound wave and dissipation of more energy and increase the sound absorption coefficient [176]. On the other hands, increased in the needle depth beyond optimum levels leads to increase the fibre damage.

Samples' results indicate that an increase in the proportion of milkweed fibres in blend leads to give higher sound absorption coefficient value at a higher frequency. Although the results showed an increase in stroke frequency, carded web mass per unit area and needle depth improves the sound absorption coefficient value of the samples except at 7.5 mm needle depth for milkweed fibre. It was found that the sound absorption coefficient increases in direct relation to the increase in carded web mass per unit area (g/m^2) of the samples, which leads to an increase in tortuosity of the samples and the energy losses due to frictional resistance. Finally, it is observed that various process parameters and interaction of various parameters gives highest sound absorption coefficient value at frequency 6300 Hz.

5.2.6 Effect of fabric thickness on the sound absorption coefficient

Table 5.25: Average sound absorption coefficient value of milkweed fibre samples for different fabric thickness at different sound frequency

Sr. No	Fabric thickness (mm)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	500 Hz	1000 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz
1	2.09	0.02	0.07	0.12	0.18	0.34	0.44	0.51	0.64	0.74
2	2.56	0.07	0.08	0.15	0.22	0.38	0.51	0.56	0.66	0.78
3	3.27	0.08	0.11	0.16	0.25	0.43	0.51	0.62	0.73	0.83
4	3.78	0.10	0.14	0.21	0.30	0.46	0.59	0.64	0.76	0.84
5	4.78	0.17	0.20	0.26	0.36	0.56	0.63	0.74	0.82	0.91

The effect of fabric thickness on the sound absorption coefficient studied and the averaged results enumerated in Table 5.25. It indicates that sound absorption coefficient values are in the range of 0.02 to 0.74, 0.07 to 0.78, 0.08 to 0.83, 0.10 to 0.84, and 0.17 to 0.91 for fabric thickness 2.09 mm, 2.56 mm, 3.27 mm, 3.78 mm and 4.78 mm at frequency 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 2500 Hz, 3150 Hz, 4000 Hz, 5000 Hz, and 6300 Hz respectively. It was found that the sound absorption coefficient value increased with an increase in the thickness of the fabric and the frequency value.

The sound absorption coefficient value for frequency 250 Hz to 2500 Hz shows increased order with an increase in the fabric thickness and frequency value. However, its value is below 0.5, which indicates the poor performance of nonwoven needle punch fabric in terms of sound absorption properties of the fabric, except one value at 2500 Hz frequency with 4.78 thickness of the fabric. Similarly, in the frequency range 3150 Hz to 6300 Hz except for one value, all other values are above 0.5, which indicates the excellent sound absorbency of the milkweed fibre needle punch nonwoven fabric. The peak value of the sound absorption coefficient observed at 6300 Hz frequency for all thickness of the fabric and highest value 0.91 observed for 4.78 mm thickness of milkweed fibre nonwoven fabric. An increase in the thickness of the fabric indicates accommodation of more material inside the fabric structure which leads to increase the surface resistance to the incident sound wave and higher heat loss due to friction resistance offered by the material results into higher sound absorption coefficient of the fabric.

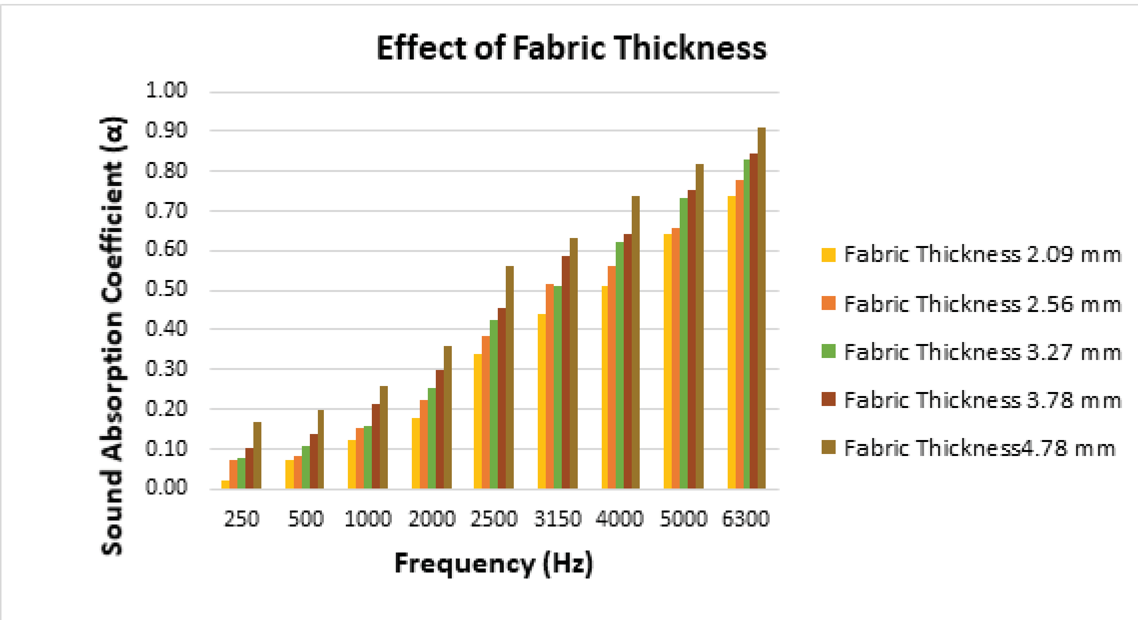

Figure 5.33: Effect of milkweed fibre fabric thickness on sound absorption coefficient

Figure 5.33 shows the sound absorption coefficient increase with the increase in the thickness of the fabric at all frequency values but givens excellent sound absorption properties between frequency 3150 Hz to 6300 Hz. The highest value of sound absorption coefficient 0.91 observed at 6300 Hz frequency with fabric thickness value 4.78 mm.

5.2.7 Effect of fabric GSM on the sound absorption coefficient

Table 5.26: Average sound absorption coefficient value of milkweed samples for different fabric GSM at different sound frequency

Sr. No	Fabric GSM (g/m^2)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	**500 Hz**	**1000 Hz**	**2000 Hz**	**2500 Hz**	**3150 Hz**	**4000 Hz**	**5000 Hz**	**6300 Hz**
1	187	0.02	0.07	0.12	0.18	0.34	0.44	0.51	0.64	0.74
2	278	0.07	0.08	0.15	0.22	0.38	0.51	0.56	0.66	0.78
3	356	0.08	0.11	0.16	0.25	0.43	0.51	0.62	0.73	0.83
4	420	0.10	0.14	0.21	0.30	0.46	0.59	0.64	0.76	0.84
5	490	0.17	0.20	0.26	0.36	0.56	0.63	0.74	0.82	0.91

The effect of fabric GSM on the sound absorption coefficient studied, and the averaged results enumerated in Table 5.26. It is observed that the sound absorption coefficient of the nonwoven samples lies in the range of 0.02 to 0.74, 0.07 to 0.78, 0.08 to 0.83, 0.10 to 0.84, and 0.17 to 0.91 for fabric GSM 187 g/m^2, 278 g/m^2, 356 g/m^2, 420 g/m^2, and 490 g/m^2 respectively. The sound absorption coefficient value for fabric GSM 187 g/m^2, 278 g/m^2, 356 g/m^2, 420 g/m^2 and 490 g/m^2 sharply increase at frequency bands 250 Hz to 6300 Hz and the maximum value of sound absorption coefficient was obtained at frequency bands 3150 to 6300 Hz, with a peak value at 6300 Hz frequency. However, Milkweed fibre fabric with GSM 187 g/m^2, 278 g/m^2, 356 g/m^2, 420 g/m^2, and 490 g/m^2 shows lower sound absorption coefficient values in frequency bands 250 Hz to 2500 Hz in comparison to higher frequency bands 3150 Hz to 6300 Hz and the value of sound absorption coefficient increases with the increasing frequency and GSM of fabric in the whole measurable frequency bands (250-6300 Hz).

Figure 5.34 shows that milkweed fibre nonwoven fabric exhibits much better sound absorption ability at frequency bands 3150-6300 Hz and increases with the increase in the fabric GSM from 187 g/m^2 to 490 g/m^2. Milkweed fibre nonwoven fabric gives the highest sound absorption coefficient at frequency 6300 Hz with 490 g/m^2. It indicates that an increase in the GSM of the fabric leads to enhance the acoustic performance of the nonwoven fabric because the increase in the fabric GSM leads to an increase in the higher number of fibre within the material, which will increase the air/fibre boundaries within nonwoven needle punch fabric. The air/fibre boundaries of nonwoven fabric will offer higher resistance to the incident sound wave and leads to an increase the sound absorbency.

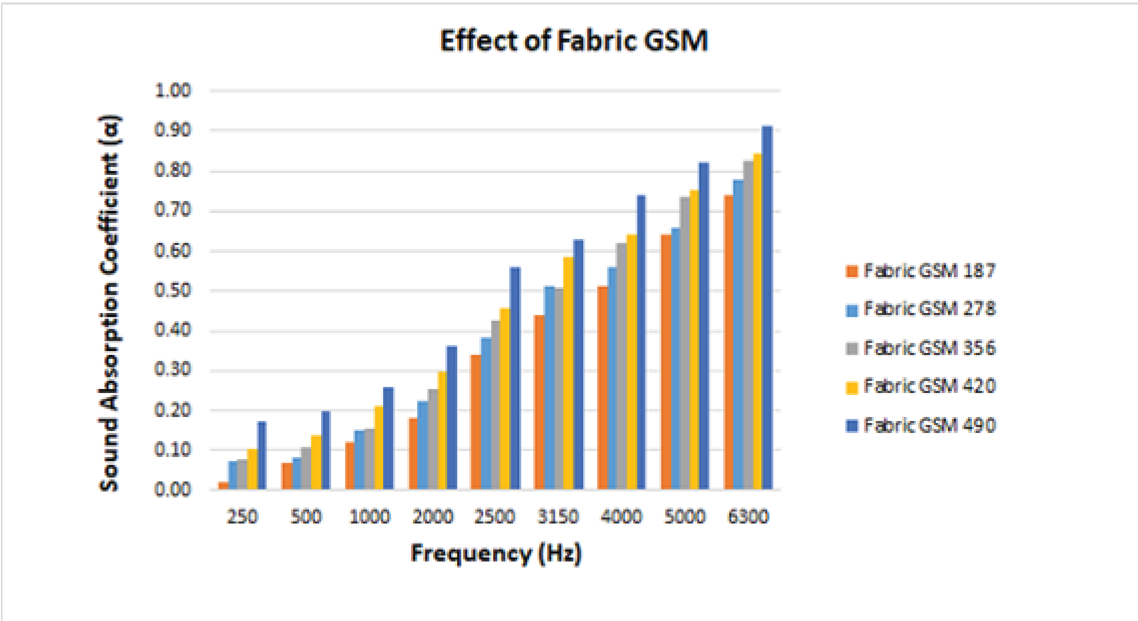

Figure 5.34: Effect of milkweed fabric GSM on sound absorption coefficient

5.2.8 Effect of fabric air permeability on the sound absorption coefficient

Table 5.27: Average sound absorption coefficient value of milkweed samples for different fabric air permeability at different sound frequency

Sr. No	Air permeability ($m^3/m^2/hr$) at 100 Pa	Sound absorption coefficient value (α) at different frequency								
		250 Hz	500 Hz	1000 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz
1	785	0.02	0.07	0.12	0.18	0.34	0.44	0.51	0.64	0.74
2	517	0.07	0.08	0.15	0.22	0.38	0.51	0.56	0.66	0.78
3	418	0.08	0.11	0.16	0.25	0.43	0.51	0.62	0.73	0.83
4	342	0.10	0.14	0.21	0.30	0.46	0.59	0.64	0.76	0.84
5	265	0.17	0.20	0.26	0.36	0.56	0.63	0.74	0.82	0.91

The effect of fabric air permeability on the sound absorption coefficient studied and the averaged results enumerated in Table 5.27. It is observed that the sound absorption coefficient of the nonwoven fabric sample shows the inverse relation between sound absorption coefficient and air permeability, which means lower air permeability of nonwoven fabric exhibits better sound absorption performance. Thus, there is some indirect relation between the sound absorption coefficient of nonwoven fabric and air permeability. It is observed that the air permeability of milkweed fibre nonwoven fabric decrease with increasing fabric thickness and fabric GSM. Nonwoven fabric with a higher value of fabric thickness and fabric GSM has less porosity and air space in the nonwoven fabric structure, which leads provide higher resistance to air and result in less air permeability. From obtained results, It is observed that sound absorption coefficient value are in the range of 0.02 to 0.74, 0.07 to 0.78, 0.08 to 0.83, 0.10 to 0.84, and 0.17 to 0.91 for air permeability value of 785, 517, 418, 342, and 265 respectively. Milkweed fibre nonwoven fabric sound absorption coefficient increased with a decrease in air permeability of fabric and increased sound wave frequency. The sound absorption coefficient of the nonwoven fabric increased with a decrease in air permeability of nonwoven fabric at fixed frequency value.

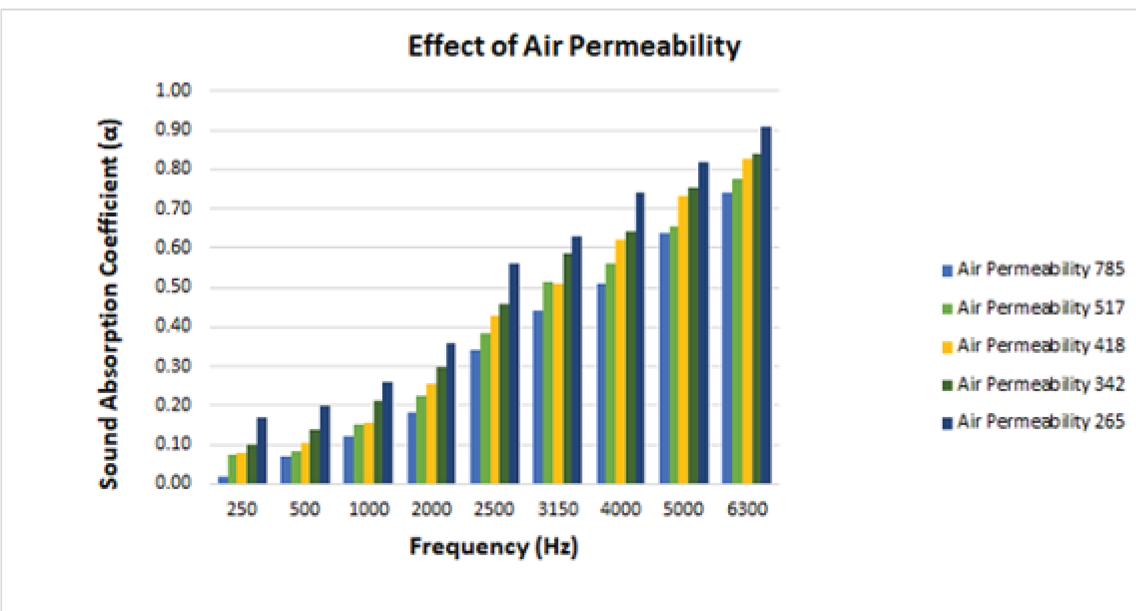

Figure 5.35: Effect of milkweed fabric air permeability on sound absorption coefficient

Figure 5.35 shows that the value of the sound absorption coefficient for fabric air permeability 785, 517, 418, 342, and 265 sharply increase at frequency bands 250 Hz to 6300

Hz and the maximum value of sound absorption coefficient was obtained at frequency bands 3150 Hz to 6300 Hz, with a peak value at 6300 Hz frequency. However, Milkweed fibre fabric with air permeability value 785, 517, 418, 342, and 265 shows lower sound absorption coefficient values in frequency bands 250 Hz to 2500 Hz in comparison to higher frequency bands 3150 Hz to 6300 Hz and the value of sound absorption coefficient increases with the increasing frequency and decrease in air permeability of fabric in the whole measurable frequency bands (250-6300 Hz). Sound absorption value above 0.5 for frequency bands 3150 Hz to 6300 Hz (except for 0.44 value at 3150 Hz for fabric air permeability 785) indicates the excellent sound absorption properties of milkweed fibre nonwoven fabric. Milkweed fibre nonwoven fabric gives the highest sound absorption coefficient value 0.91 at frequency 6300 Hz. Increased vibration of sound waves at higher frequencies resulted in frictional losses and absorption of sound energy within the structures. Thus, the sound absorption performance of milkweed nonwoven fabric improved at a higher frequency.

5.2.9 Effect of fabric porosity on the sound absorption coefficient

Table 5.28: Average sound absorption coefficient value of milkweed samples for different fabric porosity at different sound frequency

Sr. No	Fabric porosity (%)	Sound absorption coefficient value (α) at different frequency								
		250 Hz	500 Hz	1000 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz
1	92.62	0.02	0.07	0.12	0.18	0.34	0.44	0.51	0.64	0.74
2	90.89	0.07	0.08	0.15	0.22	0.38	0.51	0.56	0.66	0.78
3	90.95	0.08	0.11	0.16	0.25	0.43	0.51	0.62	0.73	0.83
4	90.82	0.10	0.14	0.21	0.30	0.46	0.59	0.64	0.76	0.84
5	91.53	0.17	0.20	0.26	0.36	0.56	0.63	0.74	0.82	0.91

The effect of fabric porosity on the sound absorption coefficient of milkweed fibre nonwoven fabric studied and the averaged results enumerated in Table 5.28. It is observed that the sound absorption coefficient of milkweed fibre nonwoven fabric shows similar trends for fabric porosity and air permeability, and it obvious that the increase in the fabric porosity leads to an increase in air permeability of the nonwoven fabric. It is observed that the porosity of milkweed fibre nonwoven fabric decrease with the increasing fabric thickness and fabric GSM because nonwoven fabric with a higher value of fabric thickness and fabric GSM have less air space in the nonwoven fabric structure.

The sound absorption coefficient values of the milkweed fibre nonwoven fabrics are increase in the range of 0.02 to 0.74 by about 3600%, 0.07 to 0.78 by about 1014%, 0.08 to 0.83 by about 938%, 0.10 to 0.84 by about 740%, and 0.17 to 0.91 by about 435%, for fabric porosity 92.62%, 90.89%, 90.95%, 90.82%, and 91.53% respectively. Similarly, the sound absorption coefficient values are increase in the range of 0.02 to 0.17 by about 750%, 0.07 to 0.20 by about 186%, 0.12 to 0.26 by about 117%, 0.18 to 0.36 by about 100%, 0.34 to 0.56 by about 65%, 0.44 to 0.63 by about 43%, 0.51 to 0.74 by about 45%, 0.64 to 0.82 by about 28%, and 0.74 to 0.91 by about 23% for frequency value of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 2500 Hz, 3150 Hz, 4000 Hz, 5000 Hz, and 6300 Hz respectively.

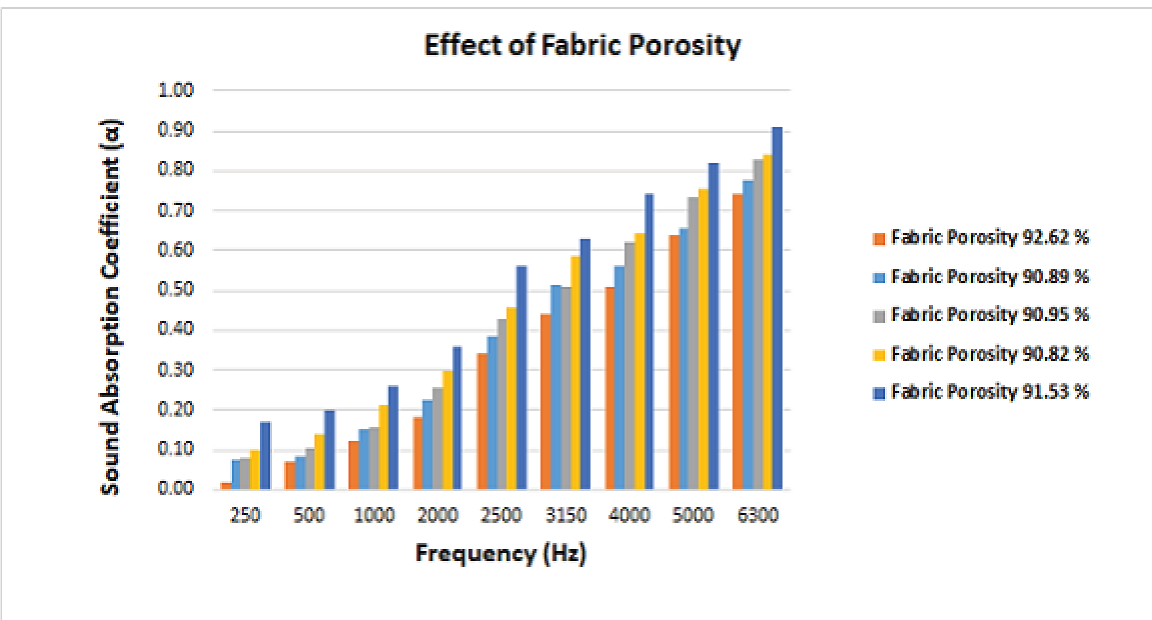

Figure 5.36: Effect of milkweed fabric porosity on sound absorption coefficient

Milkweed fibre fabric with porosity value 92.62%, 90.89%, 90.95%, 90.82%, and 91.53% shows the lower value of sound absorption coefficient in frequency bands 250 Hz to 2500 Hz in comparison to higher frequency bands 3150 Hz to 6300 Hz. The value of the sound absorption coefficient increases with the increasing frequency and decrease in porosity of fabric in the whole measurable frequency bands (250-6300 Hz), as shown in figure 5.36. Sound absorption value above 0.5 for frequency bands 3150 Hz to 6300 Hz shows good sound absorption properties of nonwoven fabric. Milkweed fibre nonwoven fabric gives the lowest value 0.02 and highest value 0.91 of sound absorption coefficient at frequency 250 Hz and 6300 Hz for fabric porosity value 92.62% to 91.53% respectively. Milkweed fibre nonwoven fabric with porosity value 91.53% gives the best sound absorption properties at 6300 Hz frequency.

5.2.10 Interactive effect of different physical properties on the sound absorption coefficient

Milkweed fibre nonwoven fabric physical properties like fabric GSM, fabric thickness, and air permeability measured in standard testing conditions. Fabric density and porosity also calculated using fabric and fibre data. The sound absorption coefficient of nonwoven fabric measured at different frequency levels. Four readings of sound absorption coefficient were taken for each sample, and the average of the obtained results along with the physical properties of fabric depicted in the Appendix II (Table 2). Here, the corresponding coded variables of fabric GSM, fabric thickness, air permeability, porosity and sound wave frequency respectively given in Table 5.29.

Table 5.29: Coded variable for physical properties of milkweed fibre fabric

Variables	Coded variables
Fabric GSM	A
Fabric Thickness (mm)	B
Air Permeability (m^3/m^2/hr)	C
Porosity (%)	D
Frequency (Hz)	E

Analysis of variance and regression analysis is used to analyze the effect of various physical parameters of milkweed fabric and its interactive effect on the sound absorption coefficient.

Table 5.30: ANOVA regression model of milkweed fabric physical properties for the sound absorption coefficient

Source	Degree of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	***F*** **Value**	***P*** **Value**
Model	54	19.0282	0.352374	779.6	< 0.001
Linear	12	2.309	0.192419	425.71	< 0.001
A	1	0.005	0.005046	11.16	0.001
B	1	0.0122	0.012239	27.08	< 0.001
C	1	0.0106	0.010577	23.4	< 0.001
D	1	0.0249	0.024864	55.01	< 0.001
E	8	2.2163	0.27704	612.93	< 0.001
Square	4	0.0217	0.005424	12	< 0.001
A^2	1	0.003	0.00297	6.57	0.011
B^2	1	0.0001	0.000102	0.23	0.635
C^2	1	0.0046	0.004588	10.15	0.002
D^2	1	0.0046	0.004644	10.27	0.002
2-Way Interaction	38	0.0773	0.002033	4.5	< 0.001
A * B	1	0.0007	0.000716	1.58	0.209
A * C	1	0.0054	0.005403	11.95	0.001
A * D	1	0.0019	0.001927	4.26	0.04
A * E	8	0.0097	0.001212	2.68	0.008
B * C	1	0.0069	0.006936	15.35	< 0.001
B * D	1	0.0052	0.005207	11.52	0.001
B * E	8	0.0131	0.00164	3.63	0.001
C * D	1	0.0078	0.007752	17.15	< 0.001
C * E	8	0.0016	0.000197	0.43	0.899
D * E	8	0.0227	0.002842	6.29	< 0.001
Error	224	0.1012	0.000452		
Total	278	19.1294			
Model Summary					

Source	Degree of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	***F*** **Value**	***P*** **Value**
Square	:	0.0212601			
R^2	:	99.47%			
R^2 (adj)	:	99.34%			
R^2 (pred)	:	99.18%			

Here, Minitab 18 software used for statistical data analysis. The effect of the measured physical property of milkweed fabric thickness, fabric GSM, air permeability, and porosity on the dependent parameter sound absorption coefficient examined for 31 milkweed fibre nonwoven fabric with analysis of variance at a significance level of value p less than 0.05. The model summary and ANOVA of obtained results depicted in Table 5.30.

Analysis of variance (ANOVA) analysis of milkweed fibre nonwoven fabric indicates that the milkweed fabric GSM, thickness, air permeability, porosity, and sound wave frequency significantly influence the sound absorption coefficient of the fabric. According to the F and p values, sound wave frequency, porosity, fabric thickness, air permeability, and fabric GSM are more significantly affect the sound absorption coefficient. It indicates that among all these fabric GMS is least affecting parameters. Along with fabric GSM type of the material and fabric structure also play a vital role in the sound absorption properties of the nonwoven fabric.

ANOVA analysis of square interaction shows that interaction between porosity and porosity, air permeability and air permeability, fabric GSM and fabric GSM, influence the sound absorption coefficient. The interaction between fabric thickness and fabric thickness seems to be less influencing factors as their p-value is 0.635. The and 2-way interaction between fabric GSM and air permeability, fabric thickness and air permeability, fabric thickness and porosity, fabric thickness and frequency, air permeability and porosity, porosity and frequency, fabric GSM and frequency, fabric GSM and porosity have a significant influence on the sound absorption value of nonwoven fabric. Statistical analysis of p-value indicates that the interaction between fabric GSM and thickness, air permeability and frequency, does not have any significant influence on the sound absorption coefficient value of milkweed fibre nonwoven fabric.

The coefficient of determination R^2 value is 99.47%, which indicates that the sound absorption coefficient of milkweed fibre nonwoven fabric is affected by fabric thickness, air permeability, porosity, fabric GSM, and sound frequency with confidence level 99.47%. The model predicts the sound absorption coefficient successfully at a level of 99.18%. The p-value of the model is < 0.001 indicates that the model is statistically highly significant.

5.2.10.1 Regression Analysis: physical properties of milkweed fibre nonwoven fabric

The regression analysis of NAC (α) versus milkweed fabric GSM, fabric thickness, air permeability and porosity without considering interactive effect of selected parameters at a various frequency discussed below. The regression equation of NAC (α) versus milkweed fabric GSM, fabric thickness, air permeability, porosity, and its interactive effect at a various frequency given in Appendix III (Table 4).

By multiple regression analysis, the coefficient of different physical properties and their probability value p-value at a 95% confidence interval were calculated with the help of Minitab 18 software, and results are shown in Table 5.31

Table 5.31: Regression Analysis: physical properties of milkweed fibre nonwoven fabric

Term	**Coef**	**SE Coef**	***P*-Value**
Constant	4.206	0.848	<0.001
A	-0.002262	0.000357	<0.001
B	0.2413	0.0406	<0.001
C	-0.000215	0.000044	<0.001
D	-0.0457	0.00976	<0.001
E			
250	0.000000	0.000000	*
500	0.0252	0.0109	0.022
1000	0.0871	0.0109	<0.001
2000	0.1742	0.0109	<0.001
2500	0.34	0.0109	<0.001
3150	0.4468	0.0109	<0.001
4000	0.5265	0.0109	<0.001
5000	0.6352	0.0109	<0.001

Term	Coef	SE Coef	P-Value
6300	0.7332	0.0109	<0.001

Following equation indicate the regression equation of sound absorption coefficient (α) versus milkweed fabric GSM, fabric thickness, air permeability and porosity without considering their interactive effect at different frequency level.

$$\begin{aligned} NAC(\alpha) = 4.206 - 0.002262A + 0.2413B - 0.000215C - 0.04570D + 0.0E(250Hz) \\ + 0.0252E(500Hz) + 0.0871E(1000Hz) + 0.1742E(2000Hz) \\ + 0.3400E(2500Hz) + 0.4468E(3150Hz) + 0.5265E(4000Hz) \\ + 0.6352E(5000Hz) + 0.7332E(6300Hz) \end{aligned} \tag{5.7}$$

From the obtained coefficient value of the parameters, it can be said that fabric thickness and sound wave frequency played a dominant role among all the selected parameters. Porosity, fabric GSM and air permeability show the impact on the sound absorption coefficient of the milkweed fibre nonwoven fabric.

The regression equation of NAC (α) versus milkweed fabric GSM, fabric thickness, air permeability, porosity, and its interactive effect at different frequency level are given in Appendix III. Following regression equation indicate the sound absorption coefficient (α) versus milkweed fabric GSM, fabric thickness, air permeability, porosity, and its interactive effect at frequency 6300 Hz.

$$\begin{aligned} NAC(\alpha) = 188.4 - 0.0654A + 13.29B + 0.03265C - 4.42D - 0.000014A * A \\ + 0.0382B * B + 0.000002C * C + 0.02606D * D + 0.00164A * B \\ - 0.000010A * C + 0.000797A * D + 0.001735B * C - 0.1596B * D \\ - 0.000394C * D \end{aligned} \tag{5.8}$$

It was observed that the best sound absorption coefficient value achieved at sound wave frequency 6300 Hz. From the above equation and Appendix III (Table 4) for the obtained coefficient value of the parameters, it can be said that the fabric thickness played a dominant role among all the selected parameters, followed by porosity, air permeability and fabric GSM. It is observed that all the selected parameters show a significant influence on the sound absorption coefficient of milkweed fibre nonwoven fabric. Other regression equations with interactive effect at various frequencies are given in Appendix III (Table 4).

In following Table 5.32 the regression coefficient values of different fabric properties are compare with each other to understand the effect of fibre type on the sound absorption coefficient.

Table 5.32: Regression coefficient: kapok vs milkweed fabric physical properties

Kapok Fibre		**Milkweed Fibre**		**Difference in coefficient value**
Term	**Coef**	**Term**	**Coef**	
A	0.0003	A	-0.0023	0.0026
B	0.0368	B	0.2413	-0.2045
C	0.0003	C	-0.0002	0.0005
D	0.0037	D	-0.0457	0.0494
E		E		
250	0.0000	250	0.0000	0.0000
500	-0.6232	500	0.0252	-0.6484
1000	-0.5442	1000	0.0871	-0.6313
2000	-0.3684	2000	0.1742	-0.5426
2500	-0.2906	2500	0.3400	-0.6306
3150	-0.1587	3150	0.4468	-0.6055
4000	-0.0842	4000	0.5265	-0.6107
5000	-0.0465	5000	0.6352	-0.6817
6300	-0.6790	6300	0.7332	-1.4122

From the obtained results it can be said that there is a difference in the coefficient value of different frequencies because the sound absorption value at different frequencies also gets affected by the types of material and its structure. In case of the milkweed fibre, fabric thickness shows a higher difference in coefficients followed by the porosity, fabric GSM, and air permeability. It indicates that fabric thickness play vital role to increase the sound absorption properties of milkweed fabric, but sound absorption value of both milkweed and kapok fibre fabric are similar, so it can be said that in case (kapok) of finer fibre with lower density it is possible to achieve same sound absorption properties with a lesser thickness of the material.

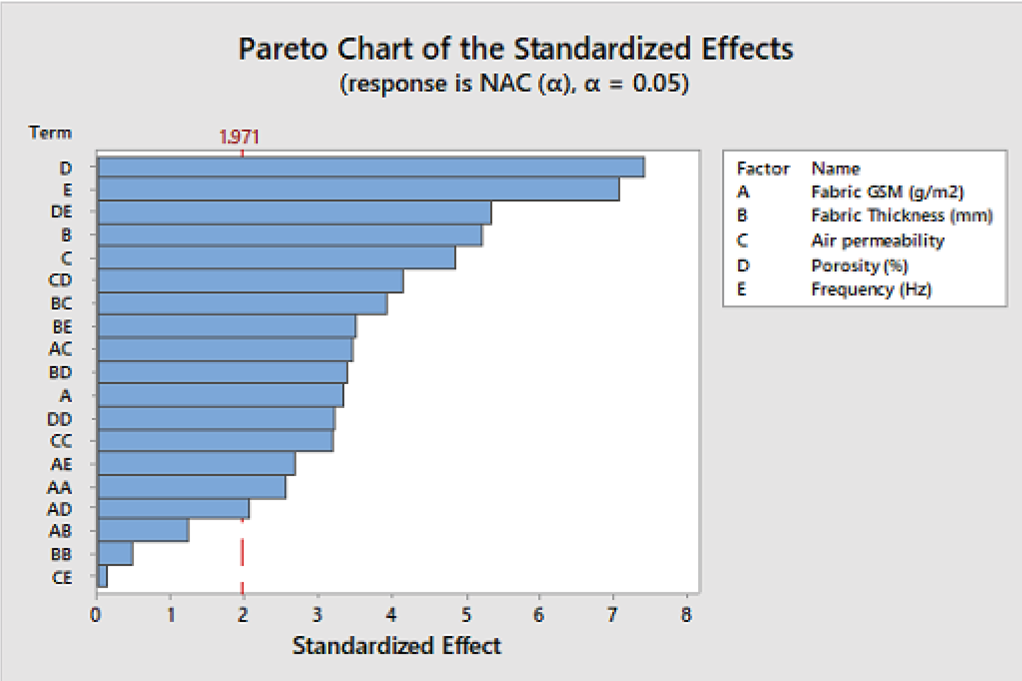

Figure 5.37: Pareto chart for physical properties of milkweed fibre nonwoven fabric

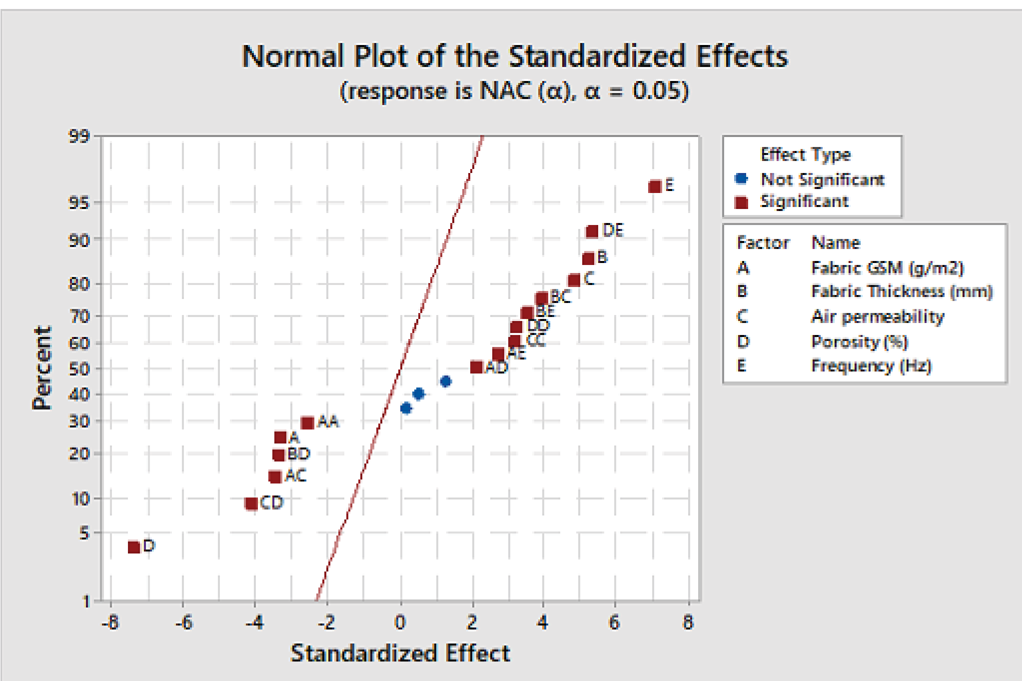

Figure 5.38: Normal plot for physical properties of milkweed fibre nonwoven fabric

The Pareto chart and Normal plot of the standardized effects for the sound absorption coefficient in Figure 5.37 and 5.38 shows porosity, and frequency has the highest effect on the sound absorption coefficient than other parameters. Fabric thickness, air permeability, fabric GSM and the interaction between porosity and frequency, air permeability and porosity, fabric thickness and air permeability, fabric thickness and frequency, fabric GSM and air permeability, fabric thickness and porosity, porosity and porosity, air permeability and air permeability, fabric GSM and frequency, fabric GSM and fabric GSM, fabric GSM and porosity significantly influence the sound absorption coefficient of milkweed fibre nonwoven fabric. The interaction between fabric GSM and thickness, fabric thickness and fabric thickness, air permeability and frequency have very less effect on the sound absorption coefficient values of Estabragh (milkweed) fibre nonwoven fabric.

5.3 Validation Test Results of Experimental Setup

Samples are tested to measure the sound absorption coefficient using the developed tube and after that tested at NBA accredited laboratory, PSGTECHS COE INDUTECH LABORATORY, Coimbatore to validate the performance and accuracy of a developed tube. It is observed that test results obtain from commercial impedance tube shown the similar trends as obtained using customized impedance tube.

The test results are given in Table 5.33 and 5.34.

Table 5.33: Comparison of sound absorption coefficient for kapok fiber nonwoven fabric

Sound Absorption Coefficient (α)-Kapok Fibre (K28)			
Frequency (Hz)	**PSG College, Impedance tube results**	**Frequency (Hz)**	**Custom-build, Impedance tube results**
250	0.04	250	0.07
500	0.06	500	0.1
1000	0.18	1000	0.21
2000	0.41	2000	0.44
2500	0.54	2500	0.52
3150	0.63	3150	0.67

Sound Absorption Coefficient (α)-Kapok Fibre (K28)			
4000	0.72	4000	0.75
5000	0.77	5000	0.76
6300	0.81	6300	0.83

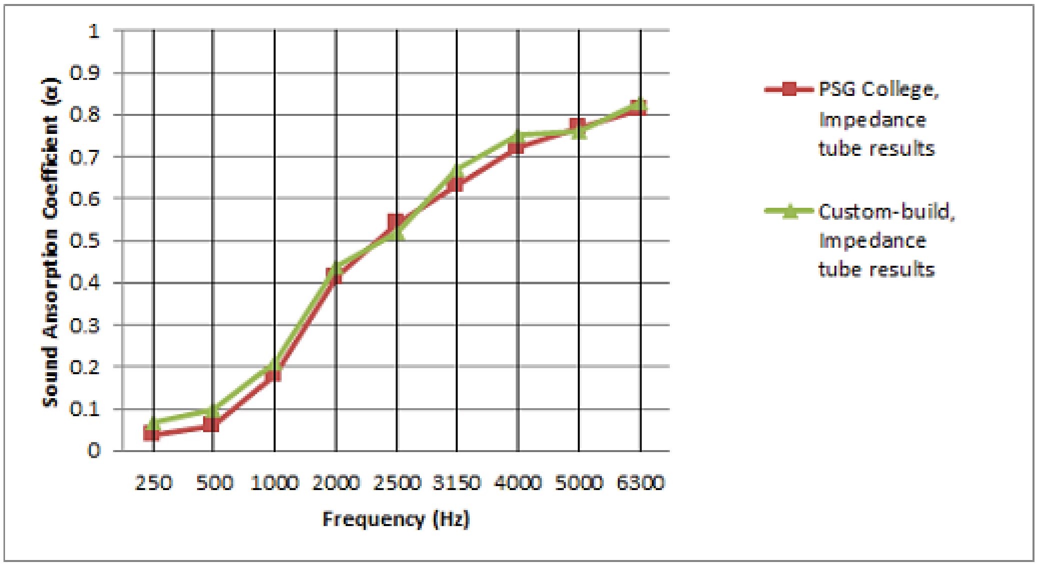

Figure 5.39: Sound absorption coefficient (α) of commercial Vs. developed tube - kapok sample

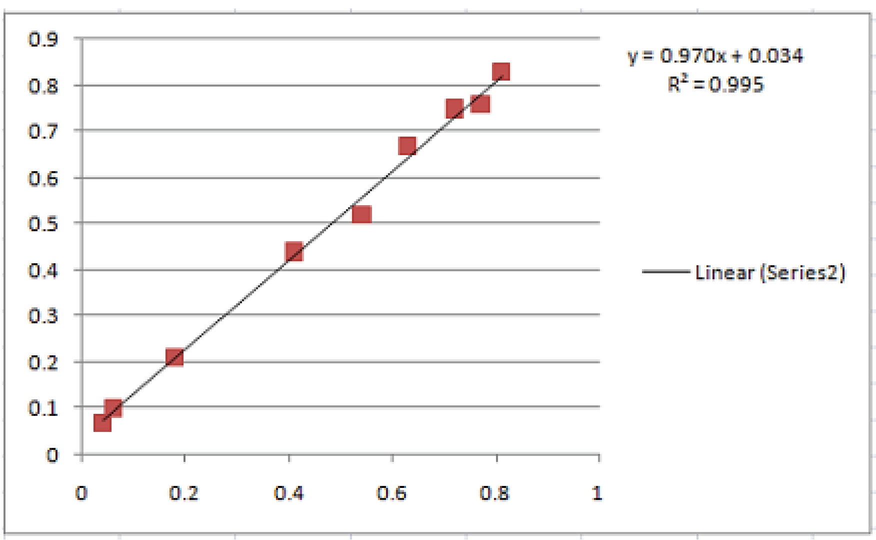

Figure 5.40: Correlation of commercial Vs. developed tube – kapok sample

Figure 5.39 shows kapok fiber non woven fabric results of sound absorption testing, while figure 5.40 shows the correlation between results obtained for kapok fiber sample using commercially available impedance tube and developed impedance tube. From figures, it is clear that both the impedance tube gives similar results, and the correlation value of r is 0.99 indicate there is a high degree of a positive linear relation between results for both the tube.

Table 5.34: Comparison of sound absorption coefficient for milkweed fiber nonwoven fabric

Sound Absorption Coefficient (α)-Milkweed Fibre (M28)			
Frequency (Hz)	**PSG College, Impedance tube results**	**Frequency (Hz)**	**Custom-build, Impedance tube results**
250	0.03	250	0.07
500	0.05	500	0.1
1000	0.11	1000	0.17
2000	0.23	2000	0.25
2500	0.36	2500	0.4
3150	0.48	3150	0.51
4000	0.61	4000	0.61
5000	0.74	5000	0.73
6300	0.81	6300	0.81

Figure 5.41 shows milkweed fiber nonwoven fabric test results in comparison with commercial and developed impedance tube. From the figure, it can be said that similar results are obtained from both tube. Figure 5.42 indicates the correlation between the sound absorption coefficient between the commercially available tube and developed tube for milkweed fiber nonwoven fabric results. Observing correlation value of r is 0.99, and the scatter diagram, it can be said that there is a high degree of linear correlation between results obtained from the commercially available tube and developed impedance tube. From obtaining results and correlation coefficient value for commercially available and developed impedance tubes, it can be said that developed impedance gives almost similar results to the commercial impedance tube. Correlation analysis also indicates that there is a high degree positive linear correlation between results obtained from the developed

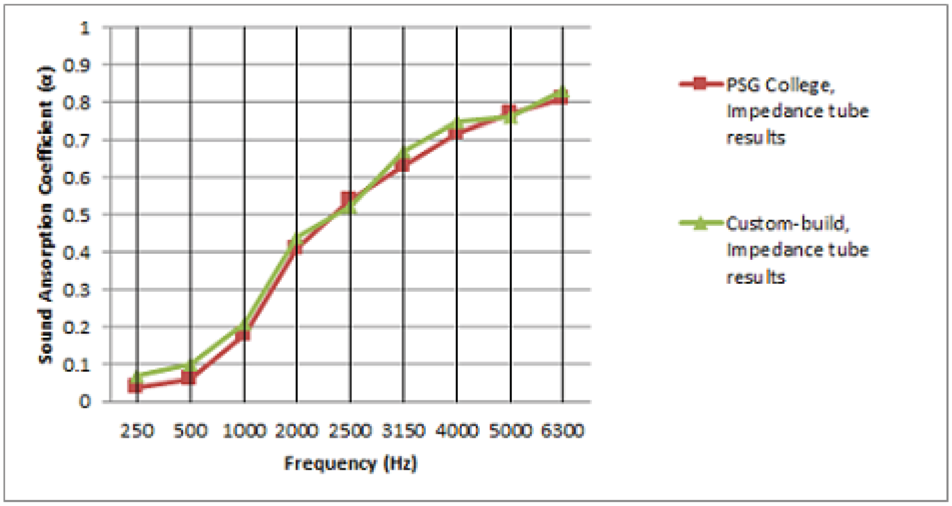

Figure 5.41: Sound absorption coefficient (α) of commercial Vs. developed tube - milkweed sample

tube and the commercial tube.

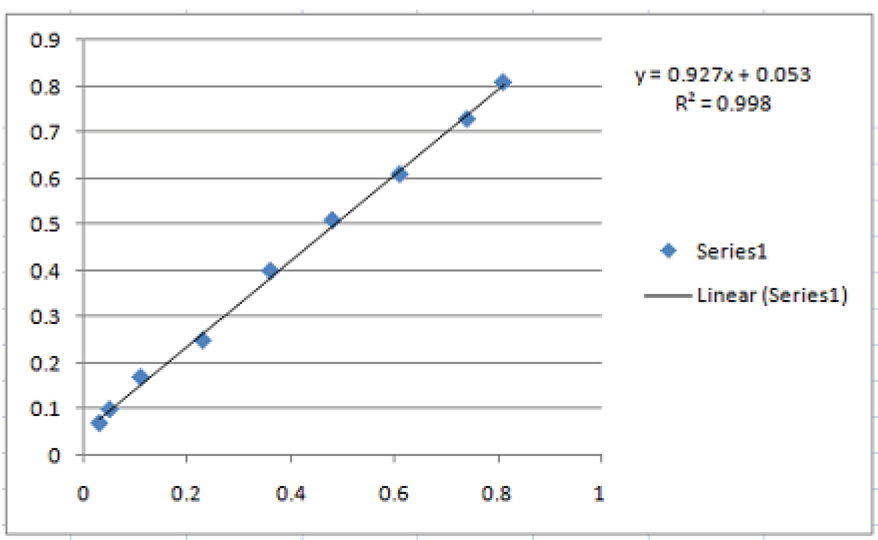

Figure 5.42: Correlation of commercial Vs. developed tube – milkweed sample

The last chapter summaries the obtained results.